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AN INTRODUCTORY COURSE IN EXPERIMENTAL PSYCHOLOGY

A TEXT-BOOK AND LABORATORY-MANUAL
FOR THE USE OF COLLEGES AND
FOR PRIVATE STUDY

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IN TWO VOLUMES

VOLUME I

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Acknowledgments

In the preparation of this volume I have gleaned from many sources. Frequently I have made explicit reference to them in the text. But it was impossible to do so consistently. So it may suffice to state here once and for all that I have used most of the text-books and laboratory-manuals available in English and in German, and in some way or other I am indebted to them all. It should be added that an explicit reference to a definite author does not imply that that author's viewpoint or theoretic interpretation is always in accord with that of the present writer.

I take this occasion to express my special indebtedness to the Rev. Joseph Fröbes, S. J., professor of Psychology in Valkenburg, Limburg, Holland, who was the first to introduce me to the subject of Experimental Psychology. His excellent Lehrbuch der experimentellen Psychologie *(Herder, Freiburg) is a complete survey of the whole field and is highly recommended for further reading.*

Unless otherwise indicated, the illustrations are made from original drawings.

Information *concerning instruments and materials needed for this introductory course in Experimental Psychology can be obtained from the publisher.*

The Author.

CONTENTS

FUNDAMENTAL CONSIDERATIONS

1. The Subject-Matter of Experimental Psychology. Anything that concerns our own dear Self is of intense interest to us. Among the things that concern each one's Self, the most fascinating are those which are not open to the gaze of all, and of which no one can have any immediate knowledge except him who experiences them. Such are the thoughts, feelings, fancies, memories, moods, aspirations, plans, wishes, resolutions, remorses, hopes, joys, sorrows, fears, likes and dislikes: in short, the whole drama which is enacted within the sanctum of each one's private Self. *These internal experiences are the subject-matter of experimental psychology.* They are the objects with which experimental psychology is *directly* concerned. *Indirectly,* however, anything that is capable of throwing light on these internal experiences—inasmuch as it is capable of doing so—comes within the scope of experimental psychology.

Prominent among the things that can throw light on our subject-matter proper are *the bodily conditions under which our mental life actually occurs.* Consequently in the course of our study we shall make an occasional sally into the field of *physiology,* particularly *the physiology of the nervous system of man.* By doing so we do not obliterate the boundary lines between psychology and physiology. We rather take into account the fact which has been recognized ever since the time of Aristotle, namely, that these bodily conditions are important factors of our mental life. Our mode of procedure, then, is in principle the same as that of Aristotle. But modern means of investigation have made it possible to apply this principle in the study of our

subject-matter more consistently and in greater detail than was possible when the science of physiology was still in its infancy.

2. The Problem of Experimental Psychology. The task which the experimental psychologist sets himself in dealing with his subject-matter may be briefly stated thus: he tries to *describe* and to *explain* our internal experiences.

An *accurate description* of our internal experiences is not so easy. For many of them are rather complex in nature. These *complex experiences must be analysed* into their component elements. In the case of the *elements* themselves we must indicate the *characteristic properties* of each and *classify* the elements according to their similarities and differences.

After this comes the still more difficult task of *explaining* our internal experiences. Why do they appear on the stage as they do, and in that particular combination, and in that particular order? What brings them on the stage and why do they disappear again as they do? What happens to them when they disappear? What brings them back again, and that in a manner which looks at times strange and bewildering? Are there definite rules concerning their appearance and disappearance? All these and similar questions must be answered when we try to explain our internal experiences.

So, *experimental psychology cannot rest satisfied with merely collecting and describing facts.* No science can. Every science aims at explaining its own group of facts. In attempting to explain our internal experiences we try to ascertain *the conditions* under which they arise. We must find out *the laws* which govern each particular experience as well as *the connection* between them all. Nor can we stop here. For the human mind is so constituted that it does not rest satisfied until it has reached *the causes* of things. If experimental psychology is to satisfy this irresistible tendency of the human mind, that is, if it is to attain to the rank of a science proper, it must of necessity

inquire into the causes of our internal experiences and their interconnection.

In the investigation of these causes we may, of course, proceed further and further. Thus we shall arrive at last at the problem concerning the ultimate source of all internal experiences: *the soul.* What is the nature of the soul and which are its essential attributes? What is its relation to the body? Whence is it and what is its destiny? What is the final aim and purpose for which the whole drama of internal experiences is enacted? In raising such problems we have reached the field which is proper to philosophy. For it is the philosopher's business to inquire into the ultimate causes of things.

Fascinating though such an inquiry is, we shall call a halt here. We do so, not because such profound problems are unanswerable, but simply because in raising them we have passed beyond the boundaries of an experimental science. We have enough work to do in dealing with the proximate causes of our internal experiences. And so, we leave it to philosophy to supplement the work which we are doing and to round it out into a more comprehensive knowledge of our subject-matter.

The inquiry into the proximate causes of our internal experiences, as understood in experimental psychology, comes practically to this. We try to correlate our internal experiences or those of a certain group of them in such a way that the properties of each and the laws which govern them become intelligible to us. And the knowledge that we thus gain must be capable of assisting us in making further investigations. Sometimes this knowledge takes the form of a mere working hypothesis. What we try to accomplish, for instance, in the chapter on the theories of color-vision is an excellent illustration of what is meant in experimental psychology by the inquiry into the proximate causes of internal experiences.

3. Observation and Experiment. If we are to describe and explain our internal experiences, we must ob-

serve them. To observe an object means to direct our attention upon it and to record as accurately as possible what has come under our notice and the conditions under which it has come under our notice. In physical sciences the objects to be observed are outside of us. Hence in observing them our attention is directed outwards; observation is inspection. In psychology the object to be observed is within us; it is an internal experience. Hence in observing it our attention must be turned inwards: *observation in psychology becomes introspection or self-observation.*

Scientific observation may be made in two ways. We may wait until the object to be observed presents itself and then observe it accurately. Thus, when a solar eclipse is to be observed, there remains nothing but to wait until it occurs. All we can do is to select the most favorable conditions for observing it. But we cannot produce the eclipse itself. Another way is to create artificially the conditions under which the very process to be observed occurs and to control these conditions in accordance with the specific aims which we have in observing it. An observation thus made is known as an experiment. An observation made in the first manner is, in opposition to experiment, known as an "observation" in the narrower sense.

Accordingly an experiment may be defined as an observation made under standard conditions, that is, under conditions which we create and control at will in accordance with the specific aims of observation.

From this it will be seen that experiment is by no means an essential feature of scientific work. There are some sciences whose subject-matter cannot be investigated by means of experiment. Such are, for instance, geology and astronomy. Nor can every problem of even an experimental science be approached from the side of experiment. This is true in particular of some problems of experimental psychology. Many occasional observations, it may be noted, have done much for the advancement of various experimental sciences (cf. Myers, Text-book of Exp. Psych., Vol. I, p. 1).

Hence, when we call the science to which this book is to introduce the student, *experimental psychology,* the meaning of the term is only this: *We put stress upon experiment in psychology, whenever its problems can be thus approached.* But we do not for all that despise observation in the narrower sense of the word. As a matter of fact, observation such as is possible outside the psychological laboratory, is, and will always remain, an important source of information in experimental psychology. *What is essential is that such observation be accurate.*

We put stress upon experiment because of its *advantages over simple observation.* These advantages are partly expressed in our very description of an experiment and need not be repeated here. We may add the following. As the conditions of an observation are accurately known, *other investigators are enabled to repeat the observation and to verify its results.* Errors of observation may thus be easily detected and eliminated and *new problems may arise. The different factors of an internal experience may be studied separately and the influence of each be determined accurately.* At times, moreover, we may give numerical expression to the results of psychological experiments by suitable *physical measurements of its external conditions.*

4. The Experimenter and the Observer in a Psychological Experiment. We referred just now to the "external" conditions of a psychological experiment. As a matter of fact there are really two sets of conditions in a psychological experiment which must be created and controlled: *external* and *internal.* The control of the external conditions consists in the suitable manipulation of the physical instruments or materials required. This is the task of the *experimenter.* He accordingly must know the aims of the experiment with precision. The internal conditions are controlled by the *observer* by simply following the instructions given him by the experimenter.

In many experiments the experimenter may be at the same time the observer. But frequently it is advisable to

divide the work between two, one being the experimenter, the other the observer. This can be done to advantage also in those experiments of this book which, as described, do not call for the co-operation of two. When this arrangement is followed, *the observer is not under the influence of suggestion,* more particularly when he does not even know what the aim of the experiment is. All he must do on his part is to carry out instructions and to report his experience with accuracy.

Further details as to the conduct of a psychological experiment are unnecessary, as the instructions given in each experiment of this book are very explicit. One general remark, however, concerning the attitude of the student in experimenting seems in place here. *The materials required for some of our experiments are of the simplest kind.* But for all that they are not toys. *The value of a psychological experiment is not measured by the cost of the brass instrument used.* It is measured by the accuracy of the observation made and the information which it yields concerning our internal life. For this purpose sometimes the simplest of materials suffice and have been handled by eminent investigators. Even the most accurate instruments of precision become toys in the hands of one who handles them without a scientific aim in view. Hence it will depend on the student whether the materials prescribed shall be toys or scientific instruments. Every experiment in this book is so devised as to mark a definite step in the acquisition of accurate information concerning our internal life. The student should perform every one of them with care and in the order assigned, or in another as the instructor may direct.

5. Physiological Psychology. We said above that bodily conditions are important factors of our mental life. It is because of this fact that the very same problems which we discuss under the heading of experimental psychology are discussed by others under the general title of *physiological psychology.* If this were all, the difference between

physiological and experimental psychology would be a merely verbal one.

Sometimes, however, in the treatment of psychological problems so much emphasis is put on the physiology of the nervous system that the boundary lines between physiology and psychology seem well-nigh obliterated. *This is particularly the case when the whole science of psychology is built upon the metaphysical assumption that the essence of mental life and of bodily life is one, or,* what comes to much the same, *the two are only different aspects of one and the same thing* . We shall discuss this assumption in due time but we cannot accept it untested from the beginning. Hence we need not state explicitly that *physiological psychology thus understood, is far from being synonymous with experimental psychology.*

As stated above, not all psychological problems can be approached by means of the psychological experiment proper. Some of these problems, however, are such that a good deal of light can be thrown on their solution by the results of experiments which are peculiar to the physiological laboratory. In the present volume no such problems come up for consideration. But some of those which we intend to treat in the next volume will be of this kind. Then we shall not consider that we leave the boundaries of *experimental* psychology proper by taking advantage of the knowledge gained in the *physiological* laboratory. For our subject-matter, as defined in the beginning, embraces indirectly anything and everything that can throw light on our mental life, and inasmuch as it can do so.

6. Plan and Purpose of this Book. This book is not a complete text-book and laboratory manual of experimental psychology. Nor is it a mere descriptive outline of the principal results achieved in the psychological laboratory. It is just what its title says: *an introductory course in experimental psychology.* This book means to introduce the student to the methods and results of experi-

mental psychology and that not merely in a descriptive manner but by leading him into the laboratory itself.

Hence a selection of psychological problems had to be made. Important topics are chosen, but those chosen are treated as thoroughly as possible without requiring very elaborate apparatus.

We begin with sensations. The reason for our doing so is not because we assume that sensations are the elements out of which our whole mental life is built up. *We make no such metaphysical assumptions.* We begin with sensations simply because our mental life begins with them. It is, however, impossible to treat all sensations experimentally within the narrow limits of an introductory course. Hence we restrict ourselves to the most important of them, namely, those of sight. There are, moreover, no sensations whose experimental investigation can give so clear an insight into what a sensation really is—in opposition to perception and other more complex processes—as visual sensations, and in particular color-sensations. *Hence the emphasis placed on the latter topic.* It should be added, however, that all such information concerning other sensations as is necessary for the understanding of subsequent problems is given incidentally, as occasion offers.

After color-sensations we take up the *visual perception of space,* a problem which is on the boundary line between the problems of sensation and perception, as will be explained later. Because of the unusual importance of this problem we treat it at some length.

Then we proceed to the problems of *attention, sense-perception,* and *imagination.* With the latter the first volume comes to a close. *We separate the general subject of sense-perception entirely from that of visual space-perception.* Our reason for doing so cannot be explained here but will become clear from the text itself.

7. A Practical Suggestion as to the Use of the Book. We begin with color-sensations. But this topic is by no means the easiest treated in this book. From a pedagogical

point of view it would be probably much better, if the order of the chapters were changed, particularly if the book is to be used for private study without an instructor. Our suggestion, then, is the following:

The student should begin with the chapter on attention and work next through the chapters on sense-perception and imagination. Then he might take up the problem of visual space-perception and only at the end work through the chapters on color-sensations. *The interest in the study of experimental psychology will be thus more effectively aroused.* Moreover, the real significance of the psychological work done in the first chapters will then be more clearly understood. The cross-references in the various chapters suppose indeed the order which they hold in the book. But this will impede the student very little in accomplishing his work successfully in the manner suggested.

CHAPTER I

COLOR-SENSATIONS

INTRODUCTORY

1. Some Preliminary Experiments on Visual Sensations in General. Their "Latent Period" and "Persistence." By way of introduction to the experimental investigation of the laws of color-sensations it may be well to consider two peculiarities of visual sensations in general which in daily life are almost entirely overlooked. In experimenting upon color-sensations we shall frequently take advantage of these peculiarities. For by doing so we are enabled, not only to dispense with some costly apparatus, but to give numerical expression to the results of our experiments, which we could not do when using some of the more elaborate apparatus. Hence these two peculiarities of every visual sensation should be clearly understood from the very outset.

The first is that a visual sensation is not strictly simultaneous with the impinging of light on the retina of the eye, but takes place a trifle after the occurrence of the latter. This is expressed in technical terms by saying that there is a "latent period" for every visual sensation. Of course, this latent period is not measured in minutes or seconds, but the unit of measurement is one-thousandth of a second, known in the psychological laboratory as a "sigma." Such delicate measurements are very difficult, and we shall not undertake them. Nor is this necessary. For a little reflection will show that such a latent period must occur. Every visual sensation depends proximately on a change set up in the organ of sight by the action of light. Of course, this material organ offers resistance to such a change: its inertia must first be overcome. The

"latent period" is really nothing else than the time during which the inertia of the organ of sight is overcome (cf. Helmholtz, Phys. Opt., pp. 480 sqq.).

The second peculiarity of every visual sensation is that it continues, after its stimulus (namely light) has been actually withdrawn, and under favorable conditions it outlasts considerably the application of the latter. It is the purpose of the following two experiments to ascertain this "persistence of visual sensations" and to measure it.

Experiment 1. Materials: A color-wheel; a black card-board disk, as described in the subsequent text; any artificial source of light, preferably an incandescent lamp. The simplest and handiest form of the "color-wheel" is a high-speed electric motor, on the shaft of which is fastened a chuck or arbor for centring and holding the disks to be rotated.

Prepare a black card-board disk of about 8 inches diameter. With a pair of scissors make a narrow radial slit in it, about 3 inches long. Near the periphery of the disk the slit should not be wider than is required to pass a visiting-card edgewise through it. This done, paste a small piece of gummed paper over the peripheral edges of the narrow slit in order to prevent their being separated and torn upon rotating the disk.

Fasten this disk on the arbor of the color-wheel and rotate it, preferably in a darkened room. An assistant should then hold an incandescent lamp just behind the rotating disk, about in the position indicated in the accompanying diagram (Fig. 1). Observe that you can see the filament of the lamp through the opaque disk as unmistakably as you did before it was screened by the latter, except that the filament is now less bright. To all practical intents and purposes the card-board has become transparent like a piece of glass, but only for objects as brilliant as the filament of the lamp, at least under the actual conditions of the experiment. This phenomenon can be easily

demonstrated to a large class, even if the slit be still narrower than here described, provided the room be dark.

Fig. 1.

What really happens in the experiment is this. When the disk is at rest and the lamp is placed behind it in the position indicated in the diagram, of course we do not see the incandescent filament. But as the disk begins to rotate, the narrow slit passes the lamp and from every portion of the incandescent filament the eye gets a momentary flick of light, which then arouses a visual sensation. (Strictly speaking we begin to see the filament only, after the slit has passed it. But this we do not prove from the present experiment.) The sensation, thus aroused, persists until the slit passes the filament for the second time, when we get another flick of the light on the same portions of the retina as the first time. If the disk rotates at the rate of 45 revolutions a second, the eye gets 45 such intermittent flicks every second. The physiological disturbances caused by them blend into one that is continuous. The result is that we do not experience a succession of visual sensations but one that is continuous. As a matter of fact, a much smaller number of revolutions per second suffices to produce a similar effect.

Now how long does the visual sensation, which is due to one of these momentary flicks of light, last? This we can determine both absolutely and relatively. To begin with the latter. Near the periphery of the disk the slit is not wider than the thickness of a visiting-card. This

means that the slit occupies about one-third of one degree of the circumference of the disk. In round numbers, then, the width of the slit is about one-thousandth portion of the periphery. Accordingly 999 portions of it are opaque. Hence the stimulus lasts one unit of time; the sensation outlasts it 999 units of time.

To determine absolutely (that is, in terms of a fraction of a second) how long the stimulus and the persistent sensation last respectively, we should have to know what fraction of a second is taken up by one revolution of the disk. If we know the speed of the electric motor, this is easily figured out.

Experiment 2. Proceed exactly as in the first experiment. But now the assistant should swing the lamp behind the disk slowly from right to left. The result of this will be that the filament is successively in different positions, when the slit passes it during the successive revolutions of the disk. Suppose the filament is in the position marked 1 in Fig. 2, when the slit passes it for the first time, and in the positions 2 and 3 respectively, when the slit passes it for the second and the third time. If the eye is steady, it will get the first momentary flick of light in one portion of the retina, the second and third flick respectively in two other portions of the retina. Each of the three flicks will cause a sensation, and each sensation will persist independently of the others.

From this experimental arrangement we see that a visual sensation may, under suitable conditions, outlast the stimulus considerably longer than a thousand times. It is not difficult to figure out how long sensation 1 has lasted, when it persists together with sensations 2 and 3.

It would, however, be very wrong to conclude from these two experiments that a visual sensation always outlasts the stimulus several thousand times. Frequently it persists only for a portion of that time during which the stimulus has acted. The time of persistence depends on a number of factors whose discussion need not detain us here. In

general it may be stated that the stronger the light, and the shorter the stimulation, the longer will the visual sensa-

Fig. 2.

tion persist. In both respects our experimental arrangements were unusually favorable. We suppose, moreover, that in making the observations the observer keeps the eye steady by fixating a definite portion of the rotating disk. All these conditions are absent in the visual sensations of daily life. Hence it is that this peculiarity of visual sensations, though universally present, is almost entirely overlooked (cf. Helmholtz, Phys. Opt., pp. 488 sqq.).

2. The So-Called "Color-Mixer." — "Color-Equations." The color-wheel is also known as the "color-mixer." This term, however, is strictly speaking a misnomer. For the color-wheel does not mix colors, either in the physical or the psychological sense, as will be explained shortly; it does, however, what is physiologically equivalent to a physical mixture of different colored lights. The student should understand this very clearly. It is the purpose of following experiments to show what really happens when we rotate colored disks by means of the color-wheel. Accordingly in the two following experiments we are not concerned with any definite law of color-mixture, but with the general phenomenon which occurs whenever we use the "color-mixer" for this purpose.

Experiment 3. Materials: A color-wheel; two colored disks, one red, the other blue, both with an accurately cut radial slit; a graduated disk to serve both as a protractor

and as a background, to prevent the colored disks from being torn upon rotation.

Prepare a compound disk by interlocking the red disk with the blue one. By means of a protractor we can measure precisely, how many degrees each of the two colored sectors of the compound disk occupies. Let us take 180 degrees of red and 180 degrees of blue. The simplest and handiest form of protractor is an accurately centered graduated disk, exhibiting the 360 degrees of the circle.

Now place the graduated disk on the arbor of the color-wheel, and over this the compound disk, and fasten both firmly on the arbor. Then set the color-wheel in rotation.

Before the rotation acquires a certain speed, the student will observe that the compound disk causes a very unsteady sensation: it exhibits various degrees of "flicker." (We are not at present concerned with this phenomenon. Here it may suffice to say that it is due to the retinal inertia spoken of in the beginning of the chapter.) As soon, however, as a certain minimum of speed is acquired, the flicker ceases and the whole disk appears uniformly purple. No further increase in the speed of rotation will bring about any change in the resulting sensation.

Now note first of all that *there occurs no physical change in the compound disk itself, except that it is rotated.* Though it looks uniformly purple, it is not uniformly in the same physical condition as a simple disk of purple paper which looks exactly like the compound disk. This can be established experimentally in more ways than one. The simple arrangement, described in the next experiment will suffice to prove this fact.

Note secondly that *there occurs no physical mixture of the two kinds of light, reflected from the two sectors of the compound disk.* For to effect such a physical mixture, both kinds of light ought to be reflected simultaneously from any given portion of the compound disk. But this is really not the case.

Note thirdly that *there occurs no psychological mixture of colors.* In other words, what occurs is not this, that we

have first the sensation of red, then that of blue, these two sensations then "fusing" into a third, namely that of purple. Introspectively the sensation of purple, aroused by the rotating disk is as simple and unanalysable into further components as is the sensation of purple aroused by a piece of ordinary purple paper.

What really happens is this. *The eye is bombarded successively by two physically different kinds of light, and this process is repeated about 50 times a second. Each of the two lights produces a specific retinal disturbance which, if not interfered with, would result in the sensations of red and blue respectively. But each retinal disturbance is interfered with by the other. The result is a compound disturbance which—as a matter of fact—causes the sensation of purple.* A plain purple disk can be found which looks exactly like the rotating compound disk, that is, which causes the same sensation as the latter.

We can express this result of our experiment also by the following equation: 360° Purple = 180° Red + 180° Blue. The left side of this equation stands for the continuous action of that amount and kind of light which is reflected from such a plain purple disk; the right side, for the rapid successive presentation to the eye of those amounts and kinds of light which are reflected respectively from the red and blue sectors of the compound disk. *The sign of equality denotes nothing else than the physiological equivalence of the two stimuli, thus compared in our equation.* (For an extension of the meaning of this and similar "color-equations" see the discussion of the "Talbot-Plateau law," pp. 24 sq.).

Experiment 4. Materials: The color-wheel; an ordinary mirror; a red-blue disk (like that used in Experiment 3, or any other disk with colored sectors) about 4 inches in diameter; a black card-board disk, about 8 inches in diameter, with a narrow radial slit near its periphery. The narrower the slit, the more accurate is the result of the experiment, but at the same time the more difficult

becomes accurate observation. A radial slit of about 10 degrees is for practical purposes the best.

Mount the colored compound disk on the color-wheel over the larger black disk. If the latter is not black on both sides, its black surface should be turned towards the eye of the observer. The colored disk should be well illuminated by an incandescent lamp or preferably by direct sunlight. The mirror should be placed in such a way that it casts no shadow on the colored disk and receives light only from the latter. The arrangement is indicated in the accompanying diagram (Fig. 3). Now bring the slit of the black disk into such a position that through it you can see clearly the image of the colored disk in the mirror. Shield the eye with the hand against the source of light. Then set the color-wheel in rotation. You will see the colored disk in the mirror just as you did before it began to rotate, except that it is dimmer. *Though the disk rotates at the rate of 50 revolutions a second, it seems to stand perfectly still, and one sector is red, the other blue.* When you raise your head and observe the image of the disk in the mirror directly, and not through the slit, the whole disk is uniformly purple.

Here is the reason for this phenomenon. When the radial slit passes before the eye for the first time, the eye gets a momentary glimpse of the whole disk, its two sectors affecting different portions of the retina. The disturbance thus set up in them outlasts the action of their respective stimuli. When the radial slit passes before the eye for the second time, the eye gets exactly the same momentary view of the whole disk, the various portions of the retina being stimulated again the same way as the first time. The same process is repeated over and over again, provided the observer does not move the eye. The result is that each affected portion of the retina is intermittently stimulated only by one kind of colored light, just as it would be if the disk were actually standing still. Hence it is that the rotating disk seems to stand still. If, however, the observer moves his head slightly to the right or the left, the sectors

of the disk will seem to move clockwise or counter-clockwise. The reason for the latter phenomenon is clear.

This experiment proves that the compound disk undergoes no physical change of color during rotation and that there occurs no physical mixture of the lights reflected from the two sectors of the disk. Each sector absorbs and reflects during rotation exactly the same light as it did before rotation.

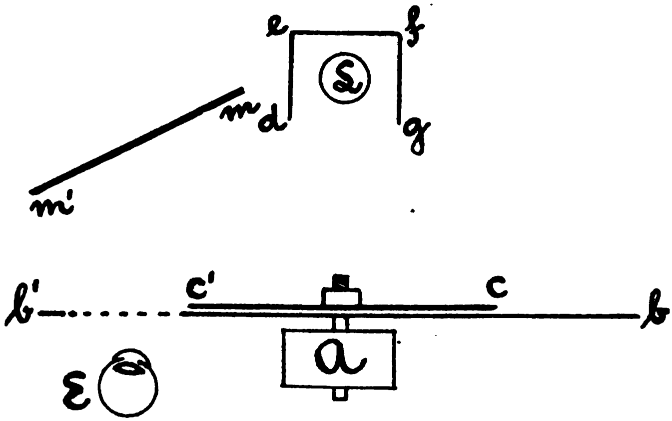


Fig. 3.—*A*, electric motor (color-wheel); *bb'*, black disk with a narrow radial slit; *cc'*, color-disk; *mm'*, mirror; *L*, tungsten incandescent lamp; *defg*, pasteboard screen; *E*, eye.

3. The Talbot-Plateau law, above referred to, may be formulated as follows: *The sensation which is produced by the rapid rotation of a disk with different colored sectors, is the same as would be produced, if all the light reflected from its several sectors were evenly distributed over the whole disk.* It may seem, at first sight, that we have proved this law already. For we have seen that a plain purple disk can be found which looks exactly like the rapidly rotated red-blue disk, that is, which causes the same sensation as the latter. The light reflected from such a plain purple disk is evenly distributed over its whole surface and reaches the eye in a state of physical mixture. But it would be very hard to prove in this instance,—

and in the case of other color-equations it would be positively false to assert,—that such a plain disk reflects a physical mixture of the identical kinds and amounts of light which are reflected separately by the sectors of a given compound disk. Accordingly to prove the Talbot-Plateau law other experimental arrangements are necessary. They are, however, too elaborate to be described here. It must suffice to state that the law has been rigorously tested and found to be valid within such limits as are always allowed for experimental error; that is: The law has been established with all the accuracy that can be desired (cf. Helmholtz, Phys. Opt., pp. 485 sqq.).

From this we draw an important practical conclusion, which it was the main purpose of this chapter to reach. It is this. *Though the color-wheel does not really mix colored lights, as we have insisted, its use is physiologically equivalent to such a real physical mixture. Accordingly, when we express the results of our experiments with the color-wheel in the form of color-equations, the latter are valid not only in the sense explained above* (p. 22), *but also in that of physical mixtures of light.* Thus, for instance, we expressed the result of experiment 3 by the following equation: 360° Purple = 180° Red + 180° Blue. We can now interpret the right side of this equation to stand for *the physical mixture of those amounts and kinds of light, which are reflected separately by the two sectors of the compound disk, supposing this mixture to be spread uniformly over the whole disk.* Though we did not ascertain the latter by direct experiment, the validity of the Talbot-Plateau law allows us to give also this meaning to our color-equation. It is thus by using the color-wheel in our experimental investigation of color-sensations that we gain the two advantages spoken of in the beginning of the chapter: We can dispense with elaborate apparatus and give numerical expression to the results of our experiments.

CHAPTER II

DEFINITION AND CLASSIFICATION OF COLOR-SENSATIONS

1. It is impossible to give a scientifically accurate definition of a definite color-sensation by a mere reference to a definite stimulus, as defined in optics.

Color-sensations are normally aroused by ether-waves of various length, amplitude, and form. The nature of this great variety of color-stimuli is investigated in that branch of physics which is known as optics. When we try to define any particular color-sensation, the most obvious thing would seem to be, simply to correlate it with a definite stimulus, as defined in optics. But an exact definition of this sort is impossible.

Thus, for instance, we cannot define the sensation of white by saying that it is a color-sensation which is aroused by what the physicist calls "white light," that is, the physical mixture of all wave-lengths of the visible spectrum, emitted by a luminous body or reflected by a non-luminous body. For such a definition would be at once too broad, and too narrow, and would, moreover, lead to rather incongruous results.

The definition would be too broad. For not only the sensation of white but also that of any shade of grey may be thus aroused. And what is still more remarkable, the sensation of green, blue, red, yellow, or any other color-tone in nature, can under appropriate conditions be produced by what the physicist calls "white light." This is, no doubt, a rather startling proposition, but none the less literally true, as we shall demonstrate experimentally in the fifth chapter.

The definition would be too narrow. For the sensation of white (and that of any shade of grey as well) can be aroused in many other ways. In fact, the number of phys-

ically different stimuli which are capable of causing the sensations of white and grey is really indefinite. To a beginner in experimental psychology this proposition must sound even more startling than the preceding one. We shall demonstrate its truth experimentally in the third chapter.

As to the incongruous results which would follow from thus defining the sensation of white, it may suffice to point out the following. On this plan the sensation of black ought to be defined as a color-sensation which is due to the absence of all physical stimuli. For no one can doubt that the sensation of black is a positive sensation, as positive and real in our internal experience as that of any other color. A positive sensation, however, cannot be due simply to the absence of all physical stimuli. Nor is this, as a matter of fact, the case. To the physicist, however, a black body is one that absorbs all light, and reflects none at all. Black, physically considered, is the absence of all color-stimuli. In the fifth chapter we shall investigate the true origin of the sensation of black.

Defining, then, a definite color-sensation by a mere reference to a definite stimulus, as defined in physics, would lead us logically to the conclusion that there is a real discrepancy between physics and psychology. But there is no discrepancy between ascertained facts and laws of one science and of another. All such apparent discrepancies vanish, if we keep before our mind two facts which it is the main purpose of this chapter to inculcate. The first is: *the experimental psychologist and the physicist deal with different things.* The former deals with facts of the inner world, the latter with facts of the outer world. The second is: *the facts of the inner world, of which we are here speaking, namely color-sensations, depend on a number of other factors besides the nature of the stimuli which arouse them.*

2. Popular Descriptions of Color-Sensations. "Memory Colors." We must accordingly consider all the factors

which influence our color-sensations in order to describe them with scientific accuracy and to discover the laws which govern them. For the purposes of daily life such accuracy in describing our color-sensations and the knowledge of the laws which govern them are hardly ever required. Hence we usually pay little attention to the variations in our actual color-sensations, which are due to changes in their numerous factors.

This is not astonishing. For, to begin with, these factors are inextricably mixed up in nature. We must first artificially separate them in the laboratory, in order to realize their varying influence. And, what makes the matter still more complicated, in our adult experience we never have a simple color-sensation, in fact no simple, isolated sensation of any kind.

Thus, for instance, we never experience the simple sensation of blue or yellow. We perceive objects which are blue or yellow, or partly blue and partly yellow. Such a perception involves much more than the simple sensation of the blue or yellow or the combination of both. Apart from other external sensations which enter likewise into the perception of a definite blue object, it implies also a number of internal sensations, revivals of former sensory experiences of ours. These internal sensations or "memory images" cluster around the external sensations and supplement them. Nor is this all. For our perceptions involve also intellectual interpretations of our sensory experiences. We are not concerned here with an experimental analysis of our perceptions. This important topic will be dealt with in a future chapter. Here we wish only to emphasize the fact that *our "memory images" and intellectual interpretations influence also our mere color-sensations, or rather our descriptions of the actual color-sensations which we experience in everyday life.*

To take a concrete example. We "know" that the American flag is "red, white, and blue," and we neglect the "chance" variations in its colors, as we experience them in different circumstances. Under the actual conditions in

which I find myself here and now, the flag looks brown, grey, and black to me. (I am describing an actual experience of mine.) And a realistic painter of the "impressionist type" who aims at reproducing his immediate and momentary impressions without regard to their intellectual interpretations, will actually paint the American flag, seen under similar circumstances, in the colors brown, grey and black. But knowing that the flag is "really" red, white, and blue, we do not hesitate to describe it in its "real" colors: red, white, and blue. In doing so we have not described our actual color-sensations but what we know about the flag in the light of former experiences: *we have described the flag in our "memory-colors."* (Cf. in this connection Helmholtz, Phys. Optik., pp. 323 sq.)

We may ascertain the influence of "memory-colors" also experimentally.

Experiment 5. Materials: A sheet of white paper; a piece of red glass such as is used by photographers in the dark-room; red ink.

Look at a sheet of white paper through a piece of red glass. Under these conditions a considerable portion of the constituents of white light is absorbed by the red glass so that only red light reaches your eyes. As a result the white paper causes the sensation of red. But you "know" that the paper is "really white" and under the influence of this knowledge you underestimate the redness of the paper thus seen. Most persons will describe its color at best as a sort of whitish red.

Now write a few words on the white paper with red ink. Or, still better, have this done by somebody else, so that you do not know what he writes or on just what part of the paper he writes. Look again at the sheet of white paper through the red glass and try to read the writing. You will find to your surprise that the writing is invisible, at least in the beginning. The reason for this is that the white portion of the paper causes exactly the same sensation of red as the writing. There is absolutely no contrast

between the letters and their background: the latter looks just as red as the former. This shows how vastly you have underestimated the redness of the paper thus seen. Your "knowledge" that the latter is "really white" has changed, not your sensation, but the description of your sensation. You have not described what you actually experience but your "memory color" of the paper.

In experimenting upon color-sensations in the psychological laboratory we are expected to be impressionists. We are to observe and describe the immediate and momentary sensory impression, made upon us by color-stimuli. The more accurate we are in observing and describing what we really here and now experience, and in noting the conditions under which we have this internal experience, the more we approach the work of the experimental psychologist in dealing with color-sensations.

3. Neutral Color-Sensations. The number of distinguishable color-sensations which can be aroused by the action of ether-waves is very great. Considering them exclusively in the light of internal experience, and ignoring altogether the terminology of the physicist, we find that they can be divided into two great classes, namely neutral and chromatic color-sensations.

By the term *neutral color-sensations* we designate *the various sensations of white, grey and black.* We say the various sensations. For not only are there many different shades of grey, but also white and black are in our experience far from being uniform things. We call a piece of ordinary writing-paper white. On comparing it with a piece of baryta-paper, which is much whiter, we should rather class ordinary writing-paper as grey. The same is true in turn of baryta-paper, when compared with newly fallen snow, reflecting the dazzling light of the mid-day sun. Something similar must be said of black. Shadows are black. But some shadows are much blacker than others. The black cover of a book, when compared with a piece of black velvet, should rather be called a dark grey.

All these various sensations of white, grey, and black, can be arranged according to their brightness along a straight line (Fig. 4). In the middle of the line we have a grey of mean brightness, as near to white as it is to

Black Dark Grey Medium Grey Light Grey White

Fig. 4.

black. At one end of the line we have white, at the other black. Or more correctly, towards the one end we have the various sensations of white, towards the other those of black. König calculated the number of distinguishable color-sensations of this class at about 660 (cf. Fröbes, I, 47). In the every-day experience of most persons the number of distinguishable sensations of this class is considerably smaller, but increases with practice and attention.

They are called *neutral* color-sensations, *because they do not contain even a tinge of any definite chroma or color-tone,* such as red, green, or yellow; a condition, rarely realized in color-sensations, as we get them from objects in nature. The whitish-grey of ordinary writing-paper may, on closer inspection, have a faint, or even rather pronounced, tint of yellow. If so, the sensation does not belong to the neutral, but to the chromatic series.

4. **Chromatic color-sensations** are those of a definite color-tone, such as are exhibited by the visible spectrum, as for instance, red, green, and violet. It will not do, however, to substitute the term "spectral" for "chromatic." For there are many more sensations of the chromatic class than are afforded by the visible spectrum. Thus, for instance, the various hues of carmine and purple are not represented in the spectrum. There is nothing surprising in this, unless we confuse our distinction between neutral and chromatic colors with that which the physicist makes between "white" and "monochromatic" light. The two distinctions are far from covering each other. That of the physicist is a purely physical one. Ours is based exclusively on internal

observation, and remains entirely unaffected whether a definite chromatic color-sensation, say of orange, is due to what the physicist calls monochromatic orange light or to a mixture of different kinds of monochromatic light. Unless we keep the psychological view-point constantly before our mind, we shall find here, as elsewhere, discrepancies between physics and psychology.

The *number* of chromatic color-sensations which can be distinguished by a trained eye, is much greater than that of the neutral series. It has been estimated—I think by Sir Herschel—that workers in mosaic distinguish in the neighborhood of 30,000 of them. Nor is this the limit of color-discrimination of which we are capable. Most psychologists add several thousands to this number. König discriminated in the visible spectrum alone 165 different color-tones (cf. Fröbes, I, p. 47).

For most persons these figures are, no doubt, too high. But this is due mainly to *lack of practice and attention.* Even an untrained eye distinguishes far more chromatic color-sensations than can be designated in the English, or any other language, by specific names. Under suitable laboratory conditions, which need not be described here, every one that is not color-blind will discover in the visible spectrum alone considerably more than the traditional seven: red, orange, yellow, green, blue, indigo, violet. Our vocabulary simply gives out when we try to designate all those we distinguish by specific names. Evidently there is need of some classification of this vast number of chromatic color-sensations. And to this problem we must now turn our attention.

5. Chromatic color-sensations cannot be classified after the manner of tone-sensations. Colors have been frequently compared with tones. No wonder that attempts have been made to classify chromatic color-sensations just like tone-sensations. Hence it is hardly a digression to insert here a brief explanation of the extremely simple method employed in classifying the latter.

Every tone-sensation has *three attributes* which can be readily correlated each with a definite property of the air-waves causing the sensation. On the basis of these correlations the unwieldy number of tone-sensations (according to Külpe about 11,600) can be easily arranged into an orderly system.

The first attribute of a tone-sensation is its *pitch*, designated in musical notation by its position on the staff. It depends on the *length of the wave* and varies in direct proportion with it. The second is *loudness* which depends on the *amplitude of the wave* and likewise varies in direct proportion with it. The third is *clang-tint*, that is, the distinctive character which differentiates a tone, even of the same pitch and loudness, when played on different instruments. It depends on the *form of the wave* (that is, on its admixture with other waves, namely those of definite partials or harmonics) and in proportion as we change the form of the wave (that is, the number and relative intensity of these partials) we change also the clang-tint. Hence there is nothing simpler than the classification of tone-sensations.

Every chromatic color-sensation, too, has three attributes. The first is its *color-"tone,"* the second its *brightness*, the third its *saturation* as we shall soon explain more fully. Following out the comparison between colors and tones we might be tempted to say that color-"tone" corresponds to pitch, brightness to loudness, saturation to clang-"tint." Accordingly we might say—and it has been said—that the *"tone"* of a color-sensation depends on the *length of the ether-waves* which cause it; its *brightness* on the *amplitude of these waves;* its *saturation* on the *form of these waves*, that is, on their admixture with other waves. If these correlations were correct, the classification of chromatic color-sensations would be extremely simple and easy.

Unfortunately all these correlations are far from being correct. We shall show this at great length in the fourth chapter. There is a radical difference between the sensi-

tiveness of the eye to colors and that of the ear to tones, and this is ignored in all such comparisons between colors and tones. Our ear has a marvelous way of analysing what is fused or mixed in the stimulus. Our eye does not thus analyse, but it is no less marvelous for fusing what is distinct in the stimulus. It is because of this peculiarity of the eye that we cannot define any color-sensation by simply correlating its attributes with those of the ether-waves, as determined by the physicist. This is true not only of the sensation of white, as we insisted in the beginning of this chapter, but of every chromatic color-sensation as well. Hence we must abandon all attempts at classifying chromatic color-sensations on the basis of such correlations.

To put the matter differently, lest we be misunderstood: *We must indeed correlate color-sensations, both neutral and chromatic, with their physical stimuli.* For the nature of these stimuli is one of the factors of color-sensations. But *correlating* the latter with the former is one thing, and *defining color-sensations by such correlations* is quite another. *It is only such latter definitions that are faulty.* The correlations which we shall undertake in the following chapters can only consist in pointing out *the multiplicity of physically different stimuli which are physiologically equivalent in arousing one and the same color-sensation.* This marvelous physiological equivalence of so many physically different stimuli is but another name for the peculiarity of our organ of sight, which we referred to above, and which is ignored in all attempts to classify chromatic color-sensations after the manner of tone-sensations.

6. The Purely Psychological Classification of Chromatic Color-Sensations. Their First Attribute: Color-Tone. As stated before, all chromatic colors are distinguished from those of the neutral series by this, that they have each some definite "tone."

Color-tone cannot be defined in any other way than by

saying: it is *that characteristic of a color which we designate by such terms as red, violet, blue, orange, and so forth.* Though we cannot define these various tones by a reference to definite kinds of monochromatic light, we may illustrate the above definition by pointing, for instance, to the left and to the right end of the spectrum, and saying: they differ in tone; the former is red, the latter is violet.

This premised, let us suppose we had a specimen of each of the 30,000 colored stones which mosaic workers can tell apart, but all jumbled together in a box. We assume, moreover, that no purely white, grey, or black ones are among them, but every one of them has some definite tone. We assume, further, that the collection is complete. This means not only that there are no duplicates among them, but all distinguishable colors of the chromatic series are represented. This latter supposition is far from being correct, but it will not impede us in the work which we are to accomplish. *The student is to sort these stones,* that is, *arrange them into an orderly system,* so that any particular color can be readily found, when it is wanted. How is he to go about this?

The first thing to do would be to spread the stones out on a large table on a uniformly grey background and in such a way that all of them are equally illuminated by diffused sun-light. For they will look different in different illumination and on different backgrounds. This must be avoided. *For in sorting them the student is to guide himself exclusively by the impression the colored stones make upon his eye under uniform conditions.* He is to discover the *similarities* and *differences* which all chromatic colors have, when compared (1) *among themselves,* and (2) *with those of the neutral series,* or, what comes to the same, with white, grey, and black. On the basis of these similarities and differences, introspectively ascertained, he is to group the colored stones. *Then the classification of them will be purely psychological.* The more completely the student forgets for the time being all he knows about

the physics of light, the better. For this knowledge will at present only hamper him.

7. The Points of Comparison in Comparing Chromatic Colors Among Themselves. The Color-Square. The next thing would be to prepare a diagram like that in Fig. 5, only much larger. For a good many of the stones are to find a place on it. This diagram is known as the "color-square." The corners of it are marked R, Y, G, B, in the order here indicated. These letters stand for the color-tones red, yellow, green, and blue, respectively. It is useless to philosophise on the physics of light to find out why we give such prominence to these tones. Really, our reason for doing so has nothing to do with the physics of light. Perhaps the student has heard something about Hering's theory of color-vision and that he postulates four "Urfarben" or "original colors." The fact is, Hering's four original colors do not coincide with ours, nor has his theory anything whatever to do with our selection of the four corner-colors.

It was Leonardo da Vinci who first called attention to the importance of red, yellow, green, and blue, in classifying all chromatic colors according to their color-tone. *In comparing chromatic colors among themselves we need definite points of comparison. The said four tones are the points of comparison.* This and nothing else is the significance of the tones at the corners of the color-square.

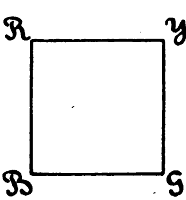


Fig. 5.—The Color-Square.

8. The Saturation of Colors. Now let the student begin his work of classification by picking out, say, all the green stones. He will not have proceeded far in his work

before he finds out that it is by no means so easy to pick out all the green stones. In some this tone is *unmistakable.* Others look rather *whitish,* others again *greyish or blackish.* In other words, there are many green stones that show an increasing similarity with white or black or one of the various shades of grey. In some, in fact, this similarity is so pronounced that they might easily be mistaken for white or black or one of the various shades of grey.

Now note: *in proportion as the tone of any chromatic color is clear, so that it cannot be mistaken for either white or black or grey, we say that the color is saturated.* This, and nothing else, is meant by the term "saturated." We need not mind the figure of speech contained in the word. That would be meddling with the physics of light and would surely get us into trouble. Whenever in future the word *"saturated"* is used in connection with chromatic colors, the student may always substitute for it *"clear," but only in the sense that the color cannot be mistaken for either white or black or grey.* For *"unsaturated"* he may always substitute *"less clear," but only in the sense that the color has an increasing similarity with either white or black or some shade of grey.*

9. Intermediate Color-Tones. For the present, then, we restrict ourselves to the classification of the "saturated" colors. We were looking for the *green* stones. As we pick them out, one after the other, a new difficulty arises. For there are a good many green stones that could indeed not be mistaken for white, black, or grey, but they show more or less similarity with blue; others, on the contrary, exhibit various degrees of similarity with yellow.

Now note: *whenever on comparing chromatic colors among themselves, we find that one of them has more or less similarity with two other chromatic colors, that color is said to be of an "intermediate tone."* Here, for instance, we found "intermediate tones" between green and blue, and likewise between green and yellow. It would not do to substitute "mixed" for "intermediate." For that again

would be meddling with physics. "Intermediate" between green and blue means nothing else than *having more or less similarity in both directions.*

10. Arranging the Saturated Colors on the Four Sides of the Color-Square. The purely psychological meaning of the terms color-tone, saturation, and intermediate color-tones being understood, we are now ready to arrange the saturated colors on the four sides of the color-square.

At the corner marked G, we place that green stone whose color is most saturated and has no similarity with either blue or yellow. Provided that there are really no duplicates among the stones, only one of them will answer this description, though several may look very much alike. An expert worker in mosaic would have to help us out in discriminating among them.

This done, we discard for the present all the yellowish-green stones, and place the other green stones on the line GB in the order of their *increasing similarity with blue* or, what comes to the same, their *decreasing similarity with green.* Thus we come at last to the place next to the corner B.

When we next pick out all the blue stones, we notice that we really have already about half their number. Those which are left, have no longer any similarity with green, but with red, except one, namely that to be placed on the corner marked B. On the line BR we arrange these stones in the order of their *increasing similarity with red,* and *decreasing similarity with blue.* Thus, to mention only those color-tones for which we have specific names, we pass over *indigo, violet, purple, carmine, magenta, and crimson* to the place next to the corner, marked R.

As may be seen, we have selected already about half the number of red stones, the other half will be yellowish, except the one, to be placed at the corner R. Arranging them on the line RY in the order of their *increasing similarity with yellow,* and *decreasing similarity with red,*

we pass over *scarlet, vermillion, orange, and gold,* to the place next to the corner Y.

There are only about half the number of yellowish stones left. They are those which we discarded, when we began to put the green ones on the line GB. At the corner Y we place that yellow stone which has similarity neither with red nor with green. The rest we arrange in the order of their *increasing similarity with green,* and *decreasing similarity with yellow.* Thus we pass over *leaf-green* to the point with which we started, namely G.

11. The Four "Psychological Primary Colors." The color-square proper is finished. It consists of four series of color-tones, arranged in the order of their similarity among themselves. There are two points of comparison for each series, G and B for the first, B and R for the second, R and Y for the third, Y and G for the fourth. The points G, B, R, and Y, are the only ones that cannot be said to have any similarity among themselves, but only, like all the rest, with white, black and grey. And with this latter similarity we have for the present nothing to do. These four points, however, connect the four series of color-tones into one that is continuous, though bent four times.

The student will see now why we made these four color-tones so prominent. *They serve as points of comparison and connecting-links for all the others and thus make the purely psychological classification of chromatic colors possible.* Accordingly we express neither a fact of optics, nor a psychological theory, but *a plain psychological fact,* when we call red, yellow, green, and blue, the "psychological primaries" among all the chromatic colors. All the others are "intermediates."

Experiment 6. Materials: the same as in Experiment 39.

As our ideal experiment with the colored stones cannot give that first-hand information which is derived from a real experiment, the instructor should perform here, by way

of demonstration, Experiment 39 of the fourth chapter. It must be emphasized, however, that the manner in which "the intermediates" are produced in this demonstration-experiment has nothing to do with the psychological classification of colors. Thus, for instance, the various hues of orange which in this experiment arise by the combination in different proportions of red and yellow, occur also in the spectrum, that is, they are not necessarily "mixed" in the physical sense.

12. The Psychological Simplicity of All "Intermediate" Colors. We insisted just now that these "intermediate" colors should not be called *"mixed" in the physical sense.* We must now insist also that they are not *"mixed" in the psychological sense.* Though we cannot express, for instance, the intermediates between green and blue by any other name than by such compounds as "greenish-blue" or "bluish-green," every one of these intermediates is just as unique and simple a color as green or blue. They do not arise in this way, that we have first a sensation of green, then another of blue, both of which then "fuse" into a compound sensation. We know nothing of this by introspection, and it would be an unwarranted assumption to suppose it to be so. Every chromatic color, represented on the sides of the color-square—and the same is true of all that remain to be classified—is exactly on a par with every other one, as far as its psychological simplicity and unique character are concerned.

13. The Color-Octahedron. We have discarded so far all the unsaturated colors. But the latter form really the bulk of chromatic colors. Most colors in nature are unsaturated: they are more or less pronounced tints or shades of the various color-tones which we have arranged along the sides of the color-square. *In the classification of these tints and shades we need new points of comparison. We must compare them with the colors of the neutral series: white, grey, and black.* This makes their classification peculiarly difficult. We must arrange them not only in

accordance with the *tone* to which each particular tint or shade belongs, but also with regard to ***their relative degree of saturation,*** and last, but not least, with regard to ***their relative brightness.*** In other words, we are about to correlate all colors of the chromatic series with those of the neutral series. Such a correlation cannot be represented diagrammatically by a plane figure but only by a model in three dimensions. It is known as the color-octahedron.

The letters R, Y, G, and B, (in Fig. 6) represent again our color-square. Through its centre (gr) we erect a vertical (bW) which stands for the series of neutral colors. The corners of the square are connected each by three straight lines with white (W), black (b), and a grey of mean brightness (gr) respectively. All the intermediate color-tones should likewise be connected each by similar straight lines with W, b, and gr. These additional lines are not represented in our diagram.

All the chromatic colors which remain to be classified must find each its proper place somewhere either on the

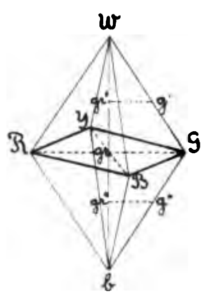


Fig. 6.—The Color-Octahedron.

outside or the inside of the model. ***The student is to determine the proper place for each.*** When he is finished with this work, he has constructed a solid double pyramid or octahedron in which every distinguishable color of both the neutral and chromatic series is represented. The position of each representative of the latter series is such that its three attributes: tone, saturation, and brightness can be determined by this position. Before we can accomplish

this most delicate portion of our work, we must explain first the purely psychological meaning of the term brightness and its relation to saturation.

14. The Purely Psychological Meaning of the Third Attribute of a Chromatic Color-Sensation: Brightness. When we began the work of classification by trying to pick out all the green stones, we found that some of them were rather whitish, others rather blackish, others again rather greyish. In other words, we found that many green stones have a decided similarity with either white, or black, or some shade of grey. In proportion as this similarity increases, the tone of the stones in question is less clear. The relative clearness of the color-tone in a given representative of the chromatic series we called its relative saturation. The relative similarity of the same representative with white, black, or some shade of grey, we call its relative brightness.

Now note: *Brightness of a chromatic color, purely psychologically considered, is nothing else than its relative similarity with white (W) and black (b).* No chromatic color is as brilliant as dazzling white, and none is as dark as jet black. All chromatic colors, the most saturated ones included, are *somewhere between white and black,* that is, *each has more or less similarity in both directions.* As a result *each representative of the chromatic series can be matched with a definite shade of grey, as far as the brightness of both is concerned.* It is by making such a match—and only thus—that the brightness of any particular color of the chromatic series is measured.

Suppose we designated the exact position of each of the 30,000 stones in our tridimensional model by a definite number, and likewise the position of each shade of grey (on the line bW of the same model) by a definite number. Then such an exact measurement would be accomplished if we could say, for instance, that number 85 of the chromatic series corresponds to number 15 of the neutral series. Both are equally bright.

Such exact measurements of the brightness of chromatic color-sensations have never been made by any one as yet, and we shall not undertake them. We must be satisfied with approximations and sometimes with rather rough ones. For even such approximations are very difficult, as it is not easy to abstract from the color-tone, when comparing the brightness of a chromatic color with that of a neutral grey.

15. The Relation between Brightness and Saturation. What makes the classification of the tints and shades still more complicated is the fact that *their brightness and saturation can be varied independently.* The principal thing to be noted in this connection is that *we can vary the saturation of a definite color-tone, say green, without changing its brightness.* Only after this is clearly understood can we indicate which stones ought to be placed on the outside of the octahedron, which on its inside, and in which order. The following real experiments will furnish the rules for finishing our ideal experiment.

Experiment 7. Materials: The color-wheel; two disks with radial slits, one of a saturated green color, the other white (baryta paper); a protractor.

Make a compound disk with green and white sectors in the proportion of 330 degrees of green to 30 degrees of white. Note the tint of green resulting from the rapid rotation of this disk. Then in successive trials increase the green sector to 60, 90, 120, 150, 180, 210, 240, 270, 300, and 330 degrees. You thus obtain some of the numerous tints situated between saturated green and neutral white.

The physical conditions under which these tints arise are irrelevant so far as the psychological arrangement of the latter is concerned. What we are to note is that we can arrange these tints along a straight line, at one end of which is saturated green, at the other, neutral white. The tints which lie between them are all of the *same tone:* green; their *saturation decreases continually,* while their *brightness increases.*

Experiment 8. Materials: The same as in the preceding experiment, except that a black disk is to be substituted for the white one.

Proceed exactly as in the preceding experiment and note that we obtain a series of shades of green. Note that these shades can be arranged along a straight line. They are all of the *same tone;* their *saturation decreases* continually, and their *brightness decreases likewise.*

Experiment 9. Materials: The same as in Experiment 7, except that a grey disk (as described in the subsequent text) is substituted for the white disk.

Choose a plain grey disk which appears to be of the same brightness as the saturated green disk. Absolute accuracy in making such a match is not required. But for the purposes of our demonstration-experiment we shall assume that both disks are absolutely equal in brightness.

Now proceed exactly as in Experiment 7. Note that we get again a series of tints of green. They can be arranged along a straight line, at one end of which is saturated green, at the other a grey of equal brightness. The tints which lie between them are all of the *same tone:* green; their *saturation decreases* continually, but their *brightness is uniformly the same.* For by supposition the plain green disk is of exactly the same brightness as the plain grey disk. Hence it makes no difference how large the sector of either green or grey is. As far as the brightness of the resulting color is concerned, one sector can be substituted for the other. Note this when we come to the arrangement of the colored stones on the inside of the color-octahedron.

Experiment 10. Materials: The same as in the preceding experiment, except that both disks are changed, as will be explained in the subsequent text.

Choose a whitish-green disk. Match it with a light-grey disk. Proceed for the rest as in the preceding experiment. Here again we get a series of tints of green which can be arranged along a straight line. At one end of this line

is *an unsaturated* (whitish) green, at the other a light *grey of equal brightness.* The tints which lie between these extremes are all of the *same tone;* their *saturation decreases* continually, but *their brightness is uniformly the same.*

Experiment 11. Materials: The same as in the preceding experiment, except that both disks are changed, as will be explained presently.

We choose now a blackish-green (olive-green) disk. We match it with a dark-grey disk. For the rest we proceed just as in the last experiment. We get a series of shades of green. They can be arranged along a straight line, at one end of which is an *unsaturated green* (olive-green), at the other, a *dark-grey of equal brightness.* The shades which lie between them are all of the *same tone;* their *saturation decreases* continually, but their *brightness is uniformly the same.*

16. The Psychological Arrangement of the Tints and Shades on the Outside and the Inside of the Color-Octahedron. To finish our ideal experiment with the colored stones we proceed as follows:

We arrange the tints of green which we obtained in Experiment 7 along the line GW of the octahedron in the order of their decreasing saturation and increasing brightness.

The shades of the same green, obtained in Experiment 8, must be placed along the line Gb in the order of their decreasing saturation and brightness.

The tints of the same green, obtained in Experiment 9, must find their places along the line Ggr in the order of their decreasing saturation.

We shall suppose that the whitish-green of the plain disk, used in Experiment 10, is represented in the color-octahedron by the point g′, and the olive-green of Experiment 11 by the point g″. Then the tints, obtained in Experiment 10 will be found along the line g′gr′, and the

shades of Experiment 11 along the line $g''gr''$, both in the order of their decreasing saturation.

In a similar manner all the other tints and shades of green as well as of every other color-tone must be arranged. When all this is done, the color-octahedron is finished.

17. The Specific Brightness of the Different Color-Tones. We said that our color-octahedron is finished. This statement needs a qualification. For in our classification of colors we have left one important fact out of consideration, the fact namely, that chromatic colors of maximal saturation differ among themselves in brightness and in saturation as well. In other words, there is a specific degree of brightness for each color-tone at which its saturation is at its maximum. A simple examination of the spectral colors, which are remarkable for their saturation, will show that they differ in both brightness and saturation. Thus, for instance, spectral yellow is evidently brighter (more similar to white) and less saturated than spectral blue, which is decidedly darker.

The relative brightness of the saturated colors is not indicated in our diagram, and that for two reasons. First of all, it is very difficult to determine their relative brightness with precision. Secondly, it is hard to represent diagrammatically what we really know about it.

Thus, for instance, we know that yellow is the brightest among the saturated colors. To represent this, we might tilt the base of the double pyramid in such a way that yellow is brought nearer to white and blue nearer to black. But by doing so we would do justice only to yellow. For now blue is represented as the darkest color. Red and green are kept at the same level, that is, they are assumed to be equally bright. The intermediate colors are represented as differing in brightness with a remarkable regularity, namely, that indicated by the sloping straight lines, connecting the corners of the color-square. But it is not true that blue is the darkest color: violet is decidedly

darker. Nor are red and green equally bright. Nor again is it true that the intermediate colors differ in brightness with that remarkable regularity which is indicated by the sloping straight lines.

Hence it does not suffice simply to tilt the base. We ought to warp and bend it besides and that without any precise rule how to warp and bend it. The color-octahedron in its present form represents more accurately what we can really accomplish in the classification of colors. Though not in every regard perfect, it had better remain as it is.

There is an obvious conclusion from the work accomplished in this chapter, which should be emphasized. Those readers who expected nothing but a review of optics under the heading of the present chapter must be now convinced that *the psychologist's study of colors is radically different from that undertaken by the physicist.*

CHAPTER III

THE SENSATIONS OF NEUTRAL WHITE AND GREY

1. The Task before Us. Colored light, impinging upon the eye, does not under all conditions produce a chromatic color-sensation. Thus, for instance, monochromatic green light of a definite wave-length does not always cause the sensation of a definite spectral green. This effect of monochromatic green light on the eye can be neutralised, that is, interfered with in such a way that the resulting sensation is not that of green but of neutral white or grey. Similarly the effect of any colored light, monochromatic or mixed, can be neutralised, and it is thus that the sensations of neutral white and grey arise in every instance.

In the present chapter we shall try to ascertain experimentally the laws which govern this neutralisation of the effect of chromatic color-stimuli or, what comes to the same, the various ways in which the sensations of neutral white and grey can be aroused. By doing so we shall prove experimentally what we said in the beginning of the last chapter, namely that there are a great many physically different stimuli—in fact indefinitely many,—which are capable of causing the sensations of white and grey.

2. The effect which any particular kind of monochromatic light would have upon the eye is neutralised when there is simultaneous action upon the eye of all the other kinds of monochromatic light. In other words, the sensations of neutral white or grey can be aroused by the physical mixture of all the various kinds of monochromatic light which, if presented singly or to different portions of the retina, would arouse respectively the sensations of the spectral colors: red, orange, yellow, green, blue, indigo, violet, and all their spectral intermediaries.

This mode of arousing the sensation of white occurs when sun-light is reflected into the eye from a body which is "physically white," that is, one that absorbs none of the incident sun-light but reflects it all. A piece of baryta paper approaches the physical condition here described.

Grey papers, reflecting sun-light, present one and the same stimulus to the eye as white bodies, only less of it. For they absorb a portion of the incident sun-light, but this absorption is equal for all the various kinds of monochromatic light into which sun-light can be resolved. Prof. Hering's series of grey papers closely approximate this physical condition.

We shall verify these statements by the following experiments.

Experiment 12. Materials: A direct-vision spectroscope, diagrammed in the accompanying figure (Fig. 7); a piece of baryta paper. As the direct-vision spectroscope is a somewhat expensive instrument, an improvised form of it may be used. The latter is described in Experiment 14.

Hold the piece of baryta paper in direct sun-light and examine the light it reflects by means of the direct-vision spectroscope. We shall observe a luminous band displaying the spectral colors: the solar spectrum.

Note the physical and physiological conditions of this phenomenon. Sunlight reflected from the sheet of baryta paper enters the narrow slit (s) of the spectroscope and is converted into a parallel beam by the convex lens (l) which is focussed on the narrow slit. This parallel beam

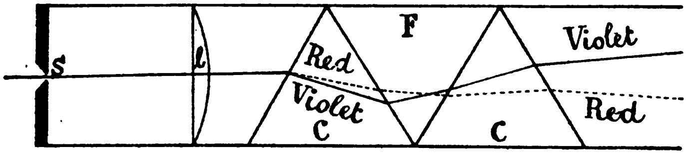


Fig. 7.—The Direct-Vision Spectroscope.

of sun-light then passes through a series of crown (C) and flint (F) glass prisms. In doing so it is refracted and dispersed into beams of different monochromatic light, the

red rays being at one end of the series, the violet at the other. For the sake of simplicity let us say that the beam of sunlight, passing through the narrow slit, has been broken up into seven divergent beams of monochromatic light. So much for the physical conditions of our experiment.

These seven divergent beams of monochromatic light now pass into the eye of the observer and affect seven different portions of the retina. Thus the effect on the retina of one kind of monochromatic light is not interfered with by that of the others. In proportion as this ideal physiological condition is realized, the observer will have seven different chromatic color-sensations, namely those of spectral red, orange, yellow, green, blue, indigo, and violet.

In referring these seven sensations back into space the eye does not follow the bending which each of the seven rays actually underwent before reaching the eye, but each impression on the retina will be referred back into space along the line of the unbroken ray which under normal conditions causes the sensation. (We shall come back to this phase of the phenomenon in the chapter on the visual perception of space.) The result is that under the artificial conditions of our experiment we really see the narrow slit seven times, once in red light, once in orange light, and so forth, and thus the narrow slit widens into the colored band we observe: the solar spectrum. In other words the seven chromatic color-sensations we have are exactly the same as we should get, if the seven rays had really originated from a colored band on the baryta paper.

The seven divergent beams can be united again, before they reach the eye, so that all of them act jointly on the same retinal elements and produce the sensation of white. Rather elaborate apparatus would be required to effect this. But such a re-combination of the divergent beams is not necessary for the experimental demonstration of the law we are considering. We simply remove the spectroscope from the eye. Then the sun-light, reflected from the

baryta paper is not physically analysed into different monochromatic lights. All the various kinds of monochromatic light reach the eye in a state of physical mixture and every portion of the eye is affected by all of them. The result is that the effect which any particular monochromatic light would have on the eye is neutralised by the action of all others, and thus we experience the sensation of neutral white.

Experiment 13. Perform the same experiment with a piece of grey paper and note that the same band of spectral colors is seen. The latter, however, are dimmer in proportion as a darker shade of grey paper is used. Consequently, other conditions being equal, it depends only on the amount of sun-light, reflected from a body, whether we see it white or some shade of grey. We shall demonstrate the latter statement with greater precision in Experiments 15 and 16.

Experiment 14. Materials: A glass-prism. Triangular crystal pendants, used as ornaments of lamps, will serve the purposes of the present experiment excellently.

Holding the book at reading distance, we shall look at Fig. 8 through a glass-prism. The latter is a substitute

Fig. 8.

for the series of prisms, contained in a direct-vision spectroscope; and the narrow white strip in a dark field takes the place of the narrow slit of the instrument.

Fig. 9 illustrates the details of the arrangement. The narrow white strip is represented by w, the dark field by dd′. We hold the prism before one eye and look in the

direction of the dotted lines. Then a beam of sunlight (wx) enters the prism and, in passing through the latter, is refracted and dispersed into its constituents of different wave-length. The longest waves will follow the path r, the shortest ones the path v. Thus lights of different wave-length will reach different portions of the retina. The result is that we see the spectrum in the direction of the dotted lines.

For the sake of simplicity we have assumed in this description that wx is a single beam of sunlight, comparable to that which passes through the narrow slit of the spectroscope. This ideal condition is only approximated. Hence the spectrum which we see is far from being pure. It really consists of various overlapping spectra, a point to which we shall return in the next chapter. The whole arrangement here described, is, however, a fairly good substitute for the expensive direct-vision spectroscope.

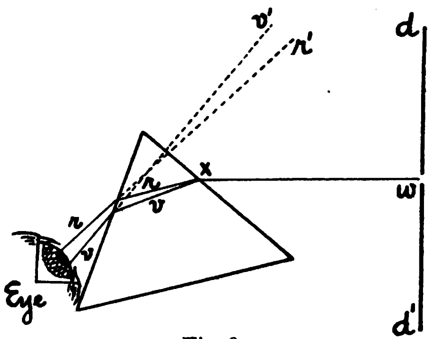


Fig. 9.

Experiment 15. Materials: The color-wheel; two disks, one black, the other white, both with radial slits; a protractor.

Interlock the white disk with the black one so that the two sectors of the compound disk occupy each 180 degrees. Note that this compound disk looks uniformly grey, when its rotation is rapid enough to extinguish flicker. For the sake of simplicity we shall assume that the black sector

really reflects no light at all. This supposed, what happens in the experiment is this.

Each revolution of the disk occupies 360 units of time. For 180 of these units every (affected) portion of the retina is stimulated simultaneously by all the different kinds of monochromatic light which are reflected from the white sector. For the subsequent 180 units of time the retina is completely shielded from this and all other stimulation. The same process is repeated over and over again. The physiological disturbance caused during the first 180 units of time, persists during the subsequent 180 units, and the successive disturbances thus caused blend into one that is continuous. Hence the sensation aroused is continuous. This sensation, however, is not that which we get by simply looking at a plain disk, made of the same white paper. According to the Talbot-Plateau law the sensation is the same as would be produced, if the same amounts and kinds of light which are reflected from the 180 degrees of the white sector, were spread uniformly over the whole disk. In other words the eye is equivalently stimulated only by one-half of the light which is reflected from a plain disk made of the same white paper. And one-half of this light produces—as a matter of fact—the sensation of a definite shade of grey.

Experiment 16. Vary the relative width of the two sectors, and note that we can thus produce the sensation of every shade of grey which lies between the black (dark grey) of the black sector and the white (very light grey) of the white sector. Note further that we can now give numerical expression to the results of our experiments, that is, we can indicate what fraction of sun-light produces (under definite conditions of illumination) the sensation of any particular shade of grey.

3. The sensation of neutral white or grey can be aroused by the combination of any two kinds of light, monochromatic or mixed, which singly would give us the sensations of complementary or antagonistic colors,

provided the strength of the two lights is appropriately regulated. If the strength of the two lights is not so regulated, the neutralisation of the sensation will be incomplete, that is, the combined stimuli will result in the sensation of an unsaturated color, whose tone is determined by the stronger component.

In dealing with this mode of arousing the sensations of neutral white and grey it is important to note that *we cannot find out by a mere comparison of two colors that they are "complementary" or "antagonistic" to each other*. Thus, for instance, on comparing a certain red with verdigris (slightly-bluish green), I find indeed that these colors differ from each other in color-tone and brightness, but I find no "antagonism" between them, any more than between the same red and emerald green.

Nor is there anything in the nature of the two physical stimuli which in a given case arouse the sensations of red and verdigris respectively to suggest any antagonism whatever. All we can find, on comparing such two stimuli, is that they differ in their physical properties, in the length, amplitude, and form of the wave. We might just as well say that seven and eight are antagonistic, but seven and nine are not antagonistic.

Nor must the term "complementary" be construed to mean that two such stimuli, acting conjointly on the eye, produce *two color-sensations which then "complement" each other* so as to form a third or compound sensation, namely that of white or grey. As far as our internal experience is concerned we know nothing of this, that the sensation of white or grey is such a psychological compound, and it would be a bit of bad metaphysics to suppose it to arise by such a process of psychological mixture.

Nor again can we say that whenever we add two such lights to each other, they "complement" each other so as to form in every instance *the same kind of physical mixture of lights,* and that the sensation of white is due in every instance to this definite mixture of lights. Such a statement would be utterly false.

It is only the ***physiological disturbances*** set up in the organ of sight by a definite pair of colored lights that are really "antagonistic" or "complementary" to each other. What is meant is this. ***When two such stimuli act jointly on the same retinal elements***—either in the state of physical mixture or in rapid alternation with each other ***—each will neutralise the specific disturbance set up by the other.*** As a result neither of the two will arouse the sensation of a chromatic color but the sensation of either neutral white or grey. In other words, the compound disturbance set up in the nervous tissue by the two stimuli is either the same as, or at least equivalent to, that which is set up by ordinary sunlight reflected from a body which is "physically white."

What pairs of light are thus capable of arousing the sensations of white and grey, we can find out only by experiment. But the knowledge we thus gain enables us to determine them independently of their physical constitution, simply in terms of the two color-sensations which such twin stimuli would arouse singly. Hence it is that we speak of the colors themselves as complementary or antagonistic.

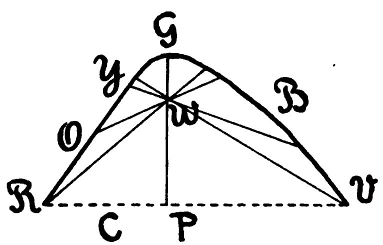


Fig. 10.—The Color-Triangle. (For details of its construction see Helmholtz, Phys. Opt., pp. 327 sqq.).

The accompanying diagram (Fig. 10), known as the "color-triangle," will assist the student in remembering which colors have been found by experiment to be complementary. (As a matter of fact, many other data concerning color-sensations are expressed in this diagram, but

they do not concern us now.) The spectral color-tones are arranged along the unbroken and somewhat curved lines of this so-called triangle, red (R), green (G), and violet (V), being at its corners. The extra-spectral color-tones are represented along the dotted line, joining red with violet. Within the triangle there is a point, marked W, which stands for white. If a straight line be drawn through this point in any direction whatever, the two color-tones which are connected by it, that is, lie at opposite ends of such a line, are complementary to each other. Thus, for instance, red and verdigris (slightly-bluish green) are complementary colors. And this means: any pairs of light, monochromatic or mixed, which arouse singly the sensations of red and verdigris respectively, will on combination produce the sensation of white or grey. Similarly orange and bluish-green, yellow and blue, yellowish-green and violet, green and purple, and so forth, are complementary colors.

Experiment 17. Materials: A color-wheel (or, preferably, two color-wheels); a protractor; pairs of color-disks, exhibiting complementary colors, such as yellow and blue, red and verdigris, etc.; two smaller disks, one white, the other black. All disks should be accurately centered and have each a radial slit.

Prepare and mount on the color-wheel a yellow-blue disk, each sector of which occupies 180 degrees. Upon rotating this compound disk it may or may not appear uniformly grey. In the latter case it will have a tinge of either yellow or blue. This means that the action of one of the two colored lights is too strong. To eliminate the tinge of yellow, the yellow sector must be made smaller, and the blue one correspondingly larger; to eliminate the tinge of blue, we must change the proportions of the two sectors in the opposite direction. Note the number of degrees which the two sectors occupy when the disk appears neutrally grey. We can now express the result of our experiment by a

color-equation, say for instance: $170° \text{ Y} + 190° \text{ B} =$ a definite shade of grey.

The right side of this equation can be expressed more accurately. That is, we can determine to how much unfiltered sun-light the colored lights, reflected from the yellow-blue disk, are physiologically equivalent. To do this, the two smaller disks, white and black, should be interlocked and mounted before the larger yellow-blue disk or preferably on a second color-wheel. The rotation of both compound disks will result in the sensation of grey, and by varying the proportions of the white and the black sectors a perfect match can be obtained between the two compound disks. Suppose such a match is obtained, when the white sector occupies 150 degrees, and the black sector 210 degrees. Then our complete color-equation will be: $170° \text{ Y} + 190° \text{ B} = 150° \text{ W} + 210° \text{ b}$. Recall what the meaning of this equation is, in terms of the Talbot-Plateau law.

We may be astonished to find that the yellow-blue disk, which looked neutrally grey in the first part of the experiment, has a decided tinge of either yellow or blue, when compared with the grey of the white-black disk. If this occurs, as in all probability it will, we must change the proportions of the colored sectors before a perfect match can be obtained. This teaches an important lesson, namely that our color-sensations, or rather our descriptions of them, depend also on the direction of our attention. The disk is the same and its effect upon the eye is the same now as it was before. In the first part of the experiment we merely overlooked the tinge of chroma which is now forced upon our attention. The same thing occurs with regard to many objects in nature which, without any standard of comparison, we commonly describe as white or grey.

Proceed in the same way with disks exhibiting other complementary colors: red and verdigris, yellowish-green and violet, green and purple, and so forth. If no change in the proportions of the sectors will eliminate all chroma

from the resulting grey, then the two colors chosen are not complementary.

For any colored disk, chosen at random, another can be found which in combination with the first will arouse the sensation of grey. It is, however, very unlikely that we shall have for every color also its complementary in our collection of colored papers.

Experiment 18. Materials: A mirror color-mixer, as described in the text; sets of colored papers, exhibiting complementary colors and mounted each on a piece of stiff card-board (about 7″ x 9″); a tungsten incandescent lamp.

The accompanying diagram (Fig. 11) represents the experimental arrangement of a mirror color-mixer. ABCD is a wooden box, blackened inside. It contains two parallel mirrors, ED and GF, set at an angle of 45 degrees to AC. These mirrors are not silvered, but transparent pieces of ordinary window glass (about 5″ x 7″ each). The right side of the box, namely BD, is open, and there is a round opening (OO′) in the centre of AB. YY′ is a sheet of yellow paper, mounted on a piece of

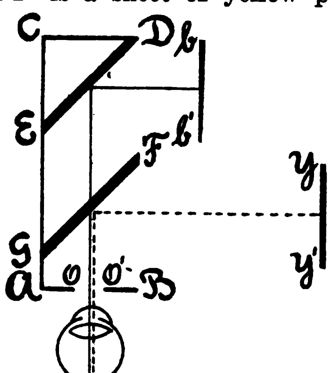


Fig. 11.

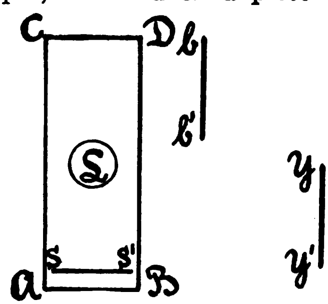


Fig. 12.

stiff card-board and set up vertically on some suitable support opposite mirror GF; bb′ a sheet of blue paper, mounted and set up similarly opposite mirror ED.

On top of the box an incandescent lamp (L) and a paste-board screen (ss′) are set up, as indicated in Fig. 12. By this arrangement the two colored papers are illuminated in such a way that no light reaches the eye of the observer except from the two colored papers. Care should be taken to avoid all shadows on the latter.

Under these conditions one mirror (ED) reflects only blue light, the other (GF) only yellow light. The path of the latter to the eye is indicated by the dotted lines, that of the former by the unbroken lines. Both colored lights thus combine and stimulate the same retinal elements. The result will be the sensation of grey, provided the strength of the two lights be appropriately regulated. This can be accomplished by varying the relative distance of the two colored papers from their respective mirrors.

When perfect neutralisation of the sensation is thus obtained, eliminate the blue light by inserting a black screen between bb′ and ED. Now only yellow light reaches the eye and we have the sensation of a definite yellow. It differs in saturation and brightness from that which we get by looking at the yellow paper directly. Insert the screen next between YY′ and GF. Now we shall have the sensation of a definite blue. The two colors which we experience under these conditions are complementary to each other. For it is only by combining the two stimuli which singly give rise to these precise color-sensations respectively that we get the sensation of neutral grey.

Proceed in the same manner to effect a physical mixture of other complementary lights.

Experiment 19. Materials: Two gelatine sheets, one yellow, the other blue.

Place one or two yellow gelatine sheets over a blue one and look through the combination at the brightly illuminated clouds. Note that the combination does not look grey but green. This agrees with the well-known practice of painters who mix yellow and blue pigments in order to

get green. But how do these facts agree with the results of Experiments 17 and 18 and with the law of complementary colors?

The answer is that in the present experiment we do not add yellow light to blue light, as the law requires. We really filter sunlight by two media of absorption and the eye is stimulated only by that portion of sun-light which is not absorbed by the two media. Mixing pigments and mixing colored lights are two very different things. It is the purpose of the present experiment to show this difference.

In the accompanying diagram (Fig. 13) bb′ stands for a blue gelatine sheet, YY′ for a yellow one. The phenomena of absorption which take place when sunlight passes through these films are rather complicated. We shall come back to this in the next chapter. In general, however, it can be said that the blue sheet absorbs principally the long waves of the spectrum (r, o, and y). Practically all the other kinds of monochromatic light are allowed to pass through it. The yellow sheet absorbs mainly the short waves of the spectrum (b and v). Only the middle portion of the spectrum, that is, green light, is transmitted through both media of absorption or, more correctly, preponderates

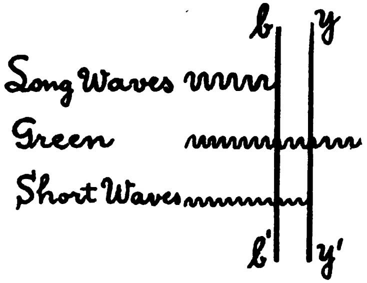


Fig. 13.

in the sum-total of light which passes through them. It is this light which reaches the eye and causes the sensation of green.

According to Helmholtz substantially the same thing

occurs, when we mix yellow and blue paints or powders. Sunlight, falling on such a mixture, is not reflected entirely from its outer surface but a good deal of it enters into the mixture. In doing so it passes successively through a number of yellow and blue pigment-particles and is filtered thereby, just as it is, when passing through the two gelatine films. Only green light is not absorbed by the pigment-particles and is reflected from their underlying surfaces. Thus green light preponderates in the sum-total of light which reaches the eye and is responsible for the sensation of green (cf. Helmholtz, Phys. Opt., p. 314).

Experiments of Helmholtz and Others with Monochromatic Light. The physical mixture of two kinds of monochromatic light presents great technical difficulties. Hence we shall be satisfied with merely recording the results of experiments performed by undoubted masters in this field of investigation. Of the many possible pairs of monochromatic light which on combination result in the sensation of white the following have been actually measured by Helmholtz. The unit of measurement for the wave-lengths of the visible spectrum is one-millionth part of a millimeter.

Color	Wavelength	Complementary Color	Wavelength	Ratio of Wavelengths
Red	656.2	Gr. Blue	492.1	1.334
Orange	607.7	Blue	489.7	1.240
Gold	585.3	Blue	485.4	1.206
Gold	573.9	Blue	482.1	1.190
Yellow	567.1	Indigo Blue	464.5	1.221
Yellow	564.4	Indigo Blue	461.8	1.222
Gr. Yellow	563.6	Violet	433 and downwards	1.301

Because of the low light-value of violet no monochromatic color was used, but all the wave-lengths from 433 down to the end of the visible spectrum were combined.

As the complementary color for green is an extra-spectral color, namely purple, green is entirely absent from the list.

Long Waves	Complementary Short Waves according to				
	v Helmholtz	v Kries	v Frey	König	Dieterici
675				496.5	
670					494.3
663				495.7	
660					494
656.2	492.1	492.4	485.2		
650				496.7	494.3
638				495.9	
635					494
626		492.2	484.6		493.1
615.3				496	
612.3		489.6	483.6		
610					492.2
607.7	489.7				
599.5		487.8	481.8		
588					485.9
587.6		484.7	478.9		
586.7			478.7		
585.7					485.7
585.3	485.4				
582.6				483.6	
579.7		478.7			
578				476.6	476.6
577.7			473.9		
577		473.9			

As will be seen from this table, as well as from the following, there is no regularity whatever discernible in the distribution of complementary colors in the visible

spectrum. *The ratio between two complementary wave lengths is neither simple nor constant.* In other words, as stated above, *there is absolutely nothing in the nature of*

Long Waves	Complementary Short Waves according to				
	v. Helmholtz	v. Kries	v Frey	König	Dieterici
576				467	
575.6					470
575.5		469.3			
574.5				455	
573.9	482.1				
573				450	
572.9		464.8			
572.8			469.3		
571.5					455
571.4					442
571.3					448
571.1		460.4			
571		452.1			
570.7			464.8		
570.4		440.4			
570.1		429.5			
569			460.4		
568.1			452.1		
567.1	464.5				
566.4			429.5		
566.3			440.4		
564.4	461.8				
563.6	433	and downwards			

any given pair of stimuli even to suggest that they are in any sense "complementary" or "antagonistic" to each other. The only regularity we can observe is their physio-

logical equivalence in producing the sensation of white and that we can always find other and other such pairs of stimuli which are likewise physiologically equivalent. What this regularity may mean in more precise physiological terms, can be only a matter of speculation when we come to consider the various theories of color-vision.

The results of similar experiments, performed by von Kries, von Frey, A. König, and C. Dieterici, are exhibited in the following table (pp. 62 and 63), in which also those of Helmholtz are repeated for comparison (cf. Helmholtz, Phys. Opt., pp. 318 sqq.).

A glance at the table shows that the results of the five experimentalists do not tally perfectly. The discrepancies are not great and are, no doubt, due in part to experimental error, which is not surprising in experimental work of so delicate a nature as this. They are, however, sufficiently great to indicate a fact which it is important to realize and which is liable to puzzle a beginner in experimental psychology. *The notable fact is: there are differences in the color-sensitivity of different individuals.* We meet the same fact frequently, when we compare the data of different observers, even if the experimental arrangement is not peculiarly elaborate, as for instance in experiments with the color-wheel. Where one observer reports: "neutral grey," another reports a slight tinge of some color-tone. It is only when such individual differences exceed a certain limit, that we speak of "subnormal" color-sensitivity or "color-weakness," and if they are striking, of "color-blindness." The color-sensitivity of the five experimentalists, represented in the above table, must, in spite of their individual differences, be classed as "normal."

4. The sensations of white and grey can be aroused by the combination of three appropriately chosen kinds of light, monochromatic or mixed, which singly would give us three different chromatic color-sensations.

We say "monochromatic or mixed," meaning thereby

that, in choosing three kinds of light we need not be concerned about their physical constitution but only with the effects which they have on the retina when presented singly and in proper combination. As a matter of fact, the manipulation of three kinds of monochromatic light is extremely difficult. Hence no experimental arrangement of this sort will be described. In Experiment 20 we shall deal with the successive presentation to the eye of three kinds of colored light, in Experiment 21 with their simultaneous presentation or physical mixture.

Experiment 20. Materials: The color-wheel (or, preferably, two color-wheels); an assortment of color-disks; two smaller disks, one white, the other black; protractor. All disks should be accurately centred and have each a radial slit.

The colors of any two disks, chosen at random, are either complementary to each other or they are not. In the latter case a disk of a third color can be found which in proper combination with the other two will result in the sensation of neutral grey. How do we find the third color? Proceed as follows.

(a) Choose two disks whose colors are evidently not complementary to each other, say red and violet. By interlocking them make a compound disk, each sector of which occupies 180 degrees. Rotate this disk on the color-wheel and observe its color. In this case it will be purple. Guiding himself by his experience in former experiments (or by the color-triangle) the student should determine which color is complementary to purple. It is green. Now make a compound disk, having three sectors of 120 degrees each, one red, the other green, the third violet. If on rotating this disk the resulting grey is tinged with a color, say with green, then the green sector must be made smaller. By thus varying the proportions of the three sectors perfect neutralisation of all chroma can be obtained.

Test the neutrality of this grey by matching it with a grey, resulting from a small white-black disk and express

the result of the experiment by a color-equation. (Proceed as directed in the second part of Experiment 17).

(b) In a similar manner try the combination in equal proportions (180° + 180°) of red and orange; red and yellow; orange and green; yellow and green; yellowish green and greenish blue; green and blue; and so forth. On finding the color which is complementary to each of these combinations, proceed as before until perfect neutralisation is obtained.

(c) Choose two colored disks at random. Even if their colors be complementary to each other, it is very unlikely that they are so when combined in equal proportions. Consequently also for such a pair a third color can be found which will lead to the desired result.

Experiment 21. An ingenious method of effecting the physical mixture of three kinds of colored light is used in color-photography and for other artistic purposes. We shall describe it in the next chapter (p. 89). The experimental arrangement there suggested may also be employed here for proving the law with which we are at present concerned.

5. The sensations of white and grey can be aroused by the (simultaneous or) successive presentation to the eye of four, five, six, seven, or any number of different kinds of colored light, (monochromatic or mixed), provided their relative strength be appropriately regulated.

Experiment 22. Materials: The color-wheel; a protractor; a selection of color-disks, made from the same papers as the disks which we employed in experimenting with two and three colors (Exp. 17 and 20). If the papers are not the same, we cannot avail ourselves of the results obtained in our former experiments.

Consult the records of Experiments 17 and 20. Suppose we find among them the following color-equations:

1. 170° Y + 190° B = neutral grey.
2. 188° P + 172° G = neutral grey.

3. 104° YG + 256° V = neutral grey.
4. 110° R + 128° G + 122° V = neutral grey.
5. 90° P + 120° YG + 150° B = neutral grey.

Now combine any two or three or four or all five disks, here recorded, into one compound disk with four, five, six, seven, or more colored sectors. In doing so we must, of course, reduce the size of the sectors but keep the same proportions. To combine for instance, disks 1 and 4, we simply reduce every colored sector to half its size. Then our compound disk will be: 85° Y + 95° B + 55° R + 64° G + 61° V. On rotating this disk we shall find that the result is a neutral grey, provided the illumination is approximately the same as in Experiments 17 and 20. If the above five-color-equations were valid only in direct sunlight, and you work now in diffused sunlight, the resulting grey will in all probability be tinged with some chroma. Then the relative size of the sectors must be varied. The reason for this will become clear from our discussion of what is known as "the threshold of color-sensation" (pp. 70 sqq.).

6. The sensation of white can be produced by any colored light whatever, provided its intensity be sufficiently increased.

Red, orange, and certain green lights, on being increased in intensity, pass through yellow, some other lights through blue, before that intensity is reached which is necessary for arousing the sensation of white.

The Cooper-Hewitt (mercury vapor) lamp, largely used in factories and wherever strong illumination is required, is a practical demonstration of the law here stated. Its light is very intense but distinctly colored. The latter is true not only in the sense that a considerable portion of the spectral wave-lengths is absent from it, but also in the sense that it will arouse the sensation of a chromatic color, provided its intensity be reduced. This occurs, when we look at such a lamp from a considerable distance. For then very little of its intense light will reach the eye.

Under such conditions it looks distinctly bluish-green. The student may ascertain this when passing a factory in which these lamps are used. When, however, he enters a room illuminated by it, and looks again at the lamp directly, it is brilliantly white. If he were to take his collection of colored papers with him and examine them in such a room, he would no longer know which is which: they all look different. Of course, the papers have the same specific power of absorption and reflection in such a room as they have outside of it. But they cannot reflect light other than they get and the color-sensations they arouse always depend on the sum-total of light which they reflect. As we judge the colors of bodies by the effect which they have on the eye in ordinary sunlight, the Cooper-Hewitt lamp cannot be used wherever color-discriminations must be made. White bodies, however, reflecting all the light they get, present a stronger stimulus to the eye and look white, when illuminated by this intense colored light.

The same law may also be verified sufficiently by the following simple arrangement.

Experiment 23. Materials: A tungsten incandescent lamp; a set of colored glasses or gelatine sheets; a piece of white paper.

Place a piece of white paper behind a tungsten incandescent lamp and hold a piece of green glass in front of the latter. We can thus see both the paper and the incandescent filament through the green glass. The light which comes directly from the filament is, of course, more intense than that reflected from the paper. Both lights, however, before reaching the eye, are filtered by the same medium of absorption. In other words, both lights are green. Under these conditions the paper will look green, but the filament will appear yellowish white.

Experimenting in the same manner with other colored glasses or gelatine sheets, we shall find that the results approximate those stated in the law (cf. Helmholtz, Phys. Opt., pp. 284-285).

When a certain kind of blue glass, known as cobalt glass, is used, the result is complicated by chromatic aberration of light in the eye. Such glass allows a small, but appreciable, portion of red light to pass through together with blue light, while the wave lengths between these extremes are fairly well absorbed. Red light, as is well known, is less refrangible than blue light. As a result these two lights, in passing through the lens and the other refractive media of the eye cannot come to exactly the same focus on the retina. Under ordinary conditions this inaccurate focussing of different kinds of light, known as chromatic aberration, is practically never noticed owing to a number of causes which need not detain us here. Under the artificial conditions of our experiment, however, it becomes distinctly noticeable. For the observer looks directly at the incandescent filament, which is so thin as to constitute practically a line-source of light, and the two waves (red and blue) which actually reach the eye differ considerably in refrangibility. The eye will naturally accommodate itself to the stronger blue light. When the latter, therefore, comes to a focus (F) on the retina, the red (indicated by the dotted lines in Fig. 14) will stimulate a larger retinal area (dd′) or, in technical language, will form a circle of diffusion. As a result of all these artificial conditions the incandescent

Fig. 14.

filament will look almost white, but it is surrounded by red fringes. The sensation of white is due to the strong blue light, that of red, to the comparatively weak red light. This is in accordance with the law stated (cf. Helmholtz, Phys. Opt., pp. 158-159).

7. **The sensations of white and grey can be aroused, or rather, they are not interfered with, by the addition**

of any colored light whatever to sun-light or any other combinatiion of lights which arouse the sensation of white or grey, provided this addition be here and now below the threshold of color-sensation.

The law, here stated, has the widest application to the sensations of white and grey as we get them in our every-day experience. It is only a special case of the more fundamental law of the "threshold," which governs all sensations without exception.

The threshold of sensation is a figure of speech, denoting that in the application of a stimulus to a sense-organ something must be "stepped over," before any conscious sensation will be aroused at all. There are lights too weak to be seen; sounds too faint to be heard; pressures too light to be felt, and so forth. *A stimulus which is just strong enough to produce a conscious sensation is known as the threshold of sensation.* This threshold is not a definite and fixed quantity of any particular form of energy, light, heat, and so forth, but it varies with the multifarious conditions under which the stimulus is applied to a sense-organ,—even with the direction of attention. The pressure exerted by the foot-wear on the small toe of the left foot, is a stimulus which in all probability has not aroused a conscious sensation in the reader whose attention is focussed on the contents of this page. The pressure was a stimulus below the threshold of sensation. Now that his attention has been called to the pressure he feels it, and if he focus his attention on it very intently, it may rise considerably above the threshold. If any one of my readers should acquire the habit of being particularly solicitous about this dear little toe of his, it will by and by cause considerable pain, and there will not be physicians enough in the land to cure it, until some one succeeds in interesting the patient in the ordinary affairs of life.

There is also a threshold in making an addition of one stimulus to another. This is known as the *"differential threshold."* The stars in the heavens are shining as brightly during the day as during the night, and the moon

reflects as much sunlight at noon-time as after sundown. But the stars are invisible during the day whilst they are seen as bright luminous specks in the firmament at night. The moon, if visible at all at noon is much paler than after sundown. The difference is this. The same amount of light, emitted by the stars, and reflected by the moon, when added to the noon-day glare of sunlight, is too slight to be perceived. It is below the threshold of vision. When the same amount of light, however, is added to the weak light which remains after sundown, it is sufficiently strong to arouse a sensation: it is above the threshold of vision. So much for the threshold of sensation in general (cf. W. Wundt, Vorlesungen, ed. 3., p. 26).

Chromatic stimuli may indeed be above the threshold of vision and still remain below the *threshold of chromatic color-sensation.* In other words, a colored light may indeed arouse a visual sensation but only one of the neutral series, not one of the chromatic series. This threshold of color-sensation again is not a fixed and definite thing. It varies with the concrete conditions, physical, physiological, and psychological, under which the colored light is applied to the eye. It varies in particular with the amount of "white light" to which it is added and with the nature of the colored light itself. Some colored lights are stronger than others, or, more correctly, the eye is more sensitive to certain kinds of colored light than to others. It is with such an addition of any colored light to any kind of "white light," that we are concerned in the following experiments (cf. Fröbes, l. c., p. 55).

Experiment 24. Materials, needed for all the remaining experiments of this chapter: The color-wheel; a protractor; a set of colored disks, including white, grey, black and deep-black (made of cloth-paper), each with a radial slit; larger white, grey, and black disks without radial slits.

Interlock a white disk with a red one. Mount the combination before a larger white disk for comparison and

rotate it in diffused sunlight. Provided the red sector be small, the addition thus made to white light will only dim the latter. That is, the compound disk will be somewhat greyish, but it will not have any colored tinge: a result which is in accord with the law stated.

Determine by successive trials the number of degrees which the red sector may have without interfering with the sensation of white. As we need the result obtained for our next experiment, let us suppose that 20 degrees of red, added to the white of baryta paper in diffused sunlight, is just below the threshold of color-sensation.

Experiment 25. Make a compound disk of a deep-black (cloth) paper and of the same red. Use a larger deep-black disk as a background. The red sector should be of the same size, as proved to be subliminal in Experiment 24, namely 20 degrees. On rotating this disk in diffused sunlight we shall find that it is distinctly colored: a result which is in accord with the law. For the black sector is not absolutely black, that is, it does not absorb all sunlight but reflects a very small (unfiltered) portion of it, probably less than 2 per cent. When we add the same amount of red light to such a small amount of white light, we add relatively more than in Experiment 24. Hence the same amount of red light which before was below the threshold of color-sensation, is now considerably above it.

Reduce the size of the red sector and thus in successive trials determine how small it must be to remain below the threshold. It will be found that under the same conditions of illumination it is practically impossible to reach this limit of color-sensitivity.

Experiment 26. Proceed in the same way with red and light-grey sectors, using the same grey as background for comparison. We shall find that the red sector must be smaller than in Experiment 24, but may be larger than in Experiment 25.

Experiment 27. Repeat Experiment 24 in direct sun-

light, and note that the red sector can be increased considerably.

Experiment 28. Repeat Experiment 25 in direct sunlight, and note that the tinge of red is even more prominent now than it was before. Of course, the illumination is the same in this as in the last experiment, but its physiological value is not the same. While the light reflected from the white sector is dazzling, in the case of the black one it is almost entirely absorbed. What is reflected will make the black paper look a dark grey. The colored light, thus increased in intensity, is relatively weak, when added to a dazzling white, but relatively strong, when added to a dark grey.

Experiment 29. Make a compound disk of white and orange, white and yellow, white and green, and so forth. Proceed as directed in Experiment 24. In determining the number of degrees which the different colored sectors may have under the same conditions of illumination (in diffused sun-light), we shall find that different colored lights differ in this regard. By noting the results of the different experiments we get a measure of the sensitivity of the eye to different colored lights. The smaller the sector must be, if it is to remain below the threshold of color-vision, the greater the sensitivity of the eye to the color of the sector.

Experiment 30. Choose two disks whose colors are complementary to each other and note the proportions of the two sectors, needed for perfect neutralisation. Then, keeping these two sectors in approximately the same proportions, insert *a third sector of any color whatever.* Provided the latter be very small, the neutralising effect of the two complementary lights will not be interfered with. If the disk has a slight tinge of chroma in diffused sunlight, you will find that it disappears in direct sunlight.

Any compound disk which has been prepared in direct sunlight and found to be neutrally grey, may and in all probability will show a tinge of some color-tone, when

rotated in diffused sunlight. The slight excess of some colored light which was subliminal in strong illumination is above the threshold in moderate illumination.

Some Practical Applications of the Law. The foam of any colored liquid looks white, though it contains the same coloring material as the rest of the liquid. The surfaces of the bubbles and the air, contained within them, act like mirrors, reflecting very strong sunlight and scattering it in all directions. Of course a portion of this light must pass through the films of the bubbles and is thereby selectively absorbed or colored. But the films are so thin that this selective absorption is very slight. The small amount of colored light, thus added to a flood of white light, does not interfere with the sensation of white: it is below the threshold of color-vision.

Window glass does not transmit all the wave-lengths of sunlight equally. Even the best optical glass only approaches this ideal condition. Hence a piece of ordinary glass of sufficient thickness, and a thin piece of it, looked at edgewise, appear distinctly greenish. But when we look at a white object through the window, we see it white. The selective absorption which white light undergoes in passing through window-glass is too slight to interfere with the sensation of white.

A crystal of molasses candy is brown, but on being crushed it looks whitish, the more so, the finer its particles. A piece of blue vitriol, in fact, any colored crystal, becomes whitish when powdered. The outer surfaces of the fine crystal particles reflect and scatter a great deal of unfiltered sunlight. Compared with this the amount of colored light which comes from the underlying surfaces of the crystal particles is too slight to interfere materially with the sensation of white. If all colored powders reflected and scattered so much unfiltered sunlight from their outer surfaces, as powdered crystals do, they would all look whitish.

White objects, seen in diffused sunlight, look indeed less

bright than in direct sunlight, but they do not appear colored, as they do when illuminated by some artificial colored light. Strictly speaking, however, diffused sunlight is colored light, differing in its physical composition from that of direct sunlight. For the diffusion of sunlight is effected by the various objects which reflect and scatter it in all directions. But many of these objects are colored, that is, they selectively absorb some constituents of sunlight, and reflect only the remnant. That this remnant is colored in the sense that it will actually arouse a chromatic color-sensation, we can ascertain readily by looking directly at a colored object. For then this remnant reaches the eye directly and causes a chromatic color-sensation, namely that of the colored object itself. When we look at a white object, the same colored light is part of the illumination. It is, however, only a slight addition to the immense flood of white light which is diffused by the sky and the clouds. Such a slight addition of colored light to white light is below the threshold of color-sensation. If, however, the walls of the room and every object in it were of uniformly the same color, say green, then such an addition of green light to white light would indeed be appreciated.

To make our account of the origin of the sensations of white and grey complete, we ought to consider also the effects of contrast and adaptation, and the peculiar condition in which the retina of color-blind persons is found, as well as that which exists normally in the peripheral portions of every retina. We shall treat of these modes of arousing the sensations of white and grey in later chapters under the respective headings indicated.

CHAPTER IV

CHROMATIC COLOR-SENSATIONS

1. **The Task before Us.** It is the purpose of the present chapter to ascertain the physical conditions under which chromatic color-sensations arise. We shall do this by establishing experimentally a number of empirical rules concerning them. Thus we shall prove at the same time what we said in the second chapter, namely, that we cannot define any chromatic color-sensation by simply correlating it with a definite stimulus, as defined in optics. The tone of a color-sensation is not defined by the length of the light-wave which causes it. Its brightness and saturation are not defined by the amplitude and form of the wave respectively.

2. **Chromatic color-sensations, as we get them from colored objects in nature, are rarely, if ever, aroused by what the physicist calls monochromatic lights, but practically in every instance by a mixture of different kinds of monochromatic light which, if presented singly or to different portions of the retina, would arouse chromatic color-sensations of other color-tones.**

Thus, for instance, the sensation of green which we get from the leaves of a tree is not due to what the physicist calls monochromatic green light. Nor is the sensation of red, obtained from a rose, due to monochromatic red light. That this is far from being true can be readily ascertained by simply analysing the light which is reflected by a green leaf or a red petal of a rose. The handiest objects to be used for such an analysis are colored papers, and these we shall employ in the following experiment.

Experiment 31. Materials: A direct-vision spectroscope; a set of colored papers (or any other colored objects); a piece of white paper.

Place a piece of white paper and a series of colored papers next to one another on a suitable support near the window. Care should be taken that the papers lie flat and cast no shadows. By means of the direct-vision spectroscope examine the light which is reflected by them. Begin with the white paper so as to get a good view of the complete solar spectrum. As we pass from the white to the first colored paper, we observe that certain portions of the spectrum are dimmed. Passing thence to the second, the third, and so forth, we find that these dimmed portions differ from one colored paper to another. But in no instance do we get a single line of monochromatic light in a completely dark field. This means that the light which is reflected from the various colored papers is in no instance monochromatic, but a mixture, made up of almost all constituents of the solar spectrum in varying proportions.

It may be objected that there is a good deal of surface reflection from all colored papers, and this consists of unfiltered sunlight and mixes with that filtered by the colored papers. This is indeed true. But it is not true that our chromatic color-sensations, as we get them from colored objects in nature, are due exclusively to that portion of sunlight which is filtered by these bodies. They are due in every instance to the sum total of the light which is reflected from them and actually reaches the eye. It is precisely this sum total which we analyse in the present experiment.

However, even the light which is filtered by colored objects, is far from being monochromatic in the majority of instances. This we shall ascertain in the next experiment.

Experiment 32. Materials: A direct-vision spectroscope; colored glasses or gelatine sheets.

Examine spectroscopically the light transmitted by some colored glass or gelatine sheet. Hold the latter against the brightly illuminated sky and directly in front of the slit of the spectroscope. We thus exclude all surface reflection and the selective absorption of sunlight, thus transmitted,

is much greater than that which takes place in the case of opaque objects. (It is owing to this greater absorption and to the absence of surface reflection that many objects look very different in transmitted and in reflected light. Thus, for instance, a very thin sheet of gold looks green in transmitted light, and yellow in reflected light.)

Yellow and green glasses, thus viewed, give practically the whole solar spectrum, though, of course, the long waves preponderate in the case of the former, and those of the middle portion in the case of the latter. Hence, when we call the light which is transmitted by these two glasses yellow and green respectively, this is true only in the sense that the mixtures which are transmitted by them cause the sensations of yellow and green respectively. Red glasses, such as are used by photographers in the dark room, give probably the nearest approach to monochromatic light, only a band of red and orange being visible in the spectrum.

Experiment 33 (a substitute for Exp. 31). Materials: A glass-prism; a piece of dull-black card-board; narrow strips of colored papers, each about one-eighth of an inch wide.

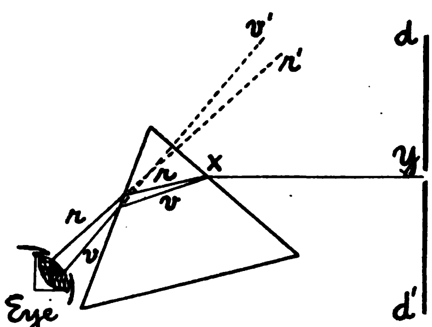


Fig. 15.

Place a narrow strip of yellow paper (Y in Fig. 15) on a piece of black card-board (dd′). Hold the latter at reading distance and view the strip of yellow paper through a glass-prism. If the beam of yellow light (Yx) which

reaches the prism were such in the sense of monochromatic light, it would be only refracted, but not dispersed in passing through the prism. As a matter of fact it is dispersed so that we see practically the whole solar spectrum in the direction of the dotted lines. Compare it with that obtained by viewing similarly a strip of white paper.

Proceed in the same manner with narrow strips of other colored papers.

Experiment 34 (a substitute for Exp. 32). Materials: A prism; a large piece of black card-board with a narrow slit (about one-eighth of an inch wide) in its centre; colored gelatine sheets.

By means of gummed paper fasten a yellow gelatine sheet behind the narrow slit of the black card-board, and place the latter in front of a window-pane. At reading distance examine the light, transmitted through the gelatine sheet by means of a prism. We find that also in this arrangement we see practically the whole solar spectrum.

In the same manner examine the light transmitted through other colored gelatine sheets.

3. The sensations of extra-spectral colors—the various hues of purple and carmine—are never aroused except by combinations of spectral lights.

The physicist knows of no monochromatic light which is carmine or purple. There are indeed light-vibrations of greater frequency than violet light, and of less frequency than red light. But the retina of the human eye is not attuned to these infra-red and ultra-violet rays. Whether there are in the animal kingdom eyes which respond to the action of ultra-violet rays with the sensations of carmine and purple, we have no means of ascertaining. In our experience the latter are never aroused except by combinations of spectral lights.

Experiment 35. Examine spectroscopically the light which is reflected from purple, carmine, magenta, or crimson papers. We find that, if the illumination is good, practically all spectral lights, and none but spectral lights

are revealed by the analysis. There is, however, a preponderance of the two ends of the spectrum.

4. Even under artificial conditions the sensations of spectral color-tones are aroused by lights which are only approximately monochromatic, that is, they are due to combinations of lights which differ somewhat in wavelength.

To what extent strictly monochromatic light can be obtained in the spectroscopic analysis of incandescent vapors, we shall not discuss here. In the case of the solar spectrum the empirical rule, here stated, surely holds.

The purity of spectral lights, as seen in the solar spectrum, depends on the narrowness of the slit through which the light, to be analysed, passes. If we widen the slit, we get also a spectrum, but it consists really of numerous overlapping spectra. The widened slit acts like a series of juxtaposed narrow slits. The beams of light which pass through them are dispersed each into a separate spectrum. By narrowing the slit we reduce the number of juxtaposed slits and consequently the overlapping of the various spectra. To get an ideal spectrum, we should have to employ a slit which is infinitesimally narrow. Then the overlapping of spectra would be infinitesimally small. But such an infinitesimally narrow slit cannot be realized, and if it could, we should not get a visible spectrum. For the infinitesimally small beam of light would be far below the limits of visibility. Practically we have the nearest approach to monochromatic lights, when the slit is so narrow that the Fraunhofer lines of absorption (black vertical lines, occupying a definite and unchangeable position in the spectrum, and due to the absorption of definite wavelengths of sunlight) are plainly visible. When we widen the slit, these black lines disappear owing to the said greater overlapping of spectra.

Experiment 36. Verify the above statements by holding the spectroscope against the brightly illuminated sky and varying the width of the slit.

Experiment 37. Materials: A glass-prism; a piece of dull-black card-board; a strip of white paper, one-eighth of an inch wide; another strip of white paper, one inch wide.

Place the narrow strip of white paper on a piece of dull-black card-board and view it at reading distance through a glass-prism. Note that the spectrum shows no Fraunhofer lines.

View similarly the wider strip of white paper and note that at reading distance you get no spectrum. The slit of the improvised spectroscope (that is, the strip of paper) is too wide. Its middle portion appears white, while its edges show colored fringes.

Red	Orange	Yellow	Green	Blue	Violet					
	Red	Orange	Yellow	Green	Blue	Violet				
		Red	Orange	Yellow	Green	Blue	Violet			
			Red	Orange	Yellow	Green	Blue	Violet		
				Red	Orange	Yellow	Green	Blue	Violet	
					Red	Orange	Yellow	Green	Blue	Violet

Fig. 16.—Colored Fringes.

This phenomenon is readily accounted for by the overlapping of different spectra, schematically represented in Fig. 16. The middle portion of the wide slit looks white, because from every point of it the eye is affected by every wave-length of the spectrum. The marginal fringes on one side are due to mixtures of the long waves, those on the other to mixtures of the short waves. It should be added that the overlapping of spectra is in reality much more complicated than our simple diagram would lead us to suppose (cf. Sanford, A Course in Exp. Psych., p. 152).

5. The sensation of one and the same color-tone can be aroused by spectral lights which differ considerably in wave-length. There is, moreover, no ascertainable ratio between changes of wave-length and changes of color-tone. Hence, when the tone of a color-sensation is compared with the pitch of a tone-sensation, such a comparison is far from being accurate even in the case of

those color-sensations which arise under the most artificial conditions.

The light-waves of the visible spectrum constitute about an octave; that is: The vibration-ratio which obtains between the longest wave (at the red end) of the visible spectrum and the shortest one (at its violet end) is—roughly speaking — the same as that between the first tone of a musical scale and its octave, namely, 1 : 2. Hence it is possible to compare the color-tones of the spectrum with the tones of a musical scale on the basis of their respective wave-lengths or vibration-frequencies. This has been done by Helmholtz (Phys. Opt., p. 288). As a result the following color-scale may be constructed (Fig. 17).

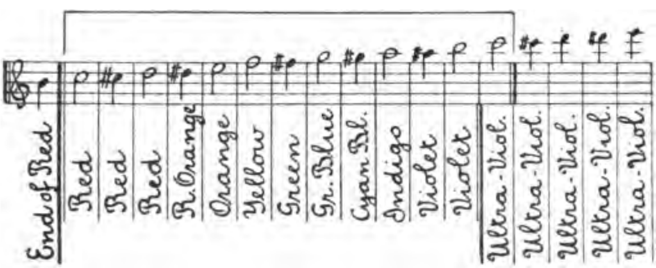


Fig. 17.—The Color-Scale (After Helmholtz, Modified).

Within the (doubly accented) octave, here represented, there are indeed only 13 musically available tones. But the number of distinguishable tones amounts to about 1,000. For practiced musicians can distinguish with certainty a difference of pitch arising from half a vibration in a second, in the octave mentioned (cf. Helmholtz, Sens. of Tone, tr. by Ellis, p. 147).

At the red end of the spectrum one and the same color-tone, namely red, is correlated with widely different wave-lengths. The ear discriminates within the same limits more than two hundred tones of different pitch. If the sensitiveness of the ear to differences in wave-length were like that of the eye, two hundred tones of different pitch (between

c″ and d″ sharp) could be sounded successively or simultaneously without any offense to the ear. In fact the whole piano could be tuned satisfactorily in a rather slipshod fashion. With certain tones, however, the tuner would have to be a little more careful.

Hence in correlating color-tones with monochromatic lights there is always a considerable leeway in one direction or the other, or both. We can understand the term ''monochromatic light'' only in the sense of an *average* wave-length. What is more, this average is not a uniform quantity. There are more spectral color-tones discernible than the nine which in our diagram are correlated with the thirteen available tones of the musical scale. It is only because most of these color-tones have been left out of consideration that there is a semblance of uniformity in the ''color-scale''.

No doubt, there is a law which governs the sensitiveness of the eye to differences in wave-length of light. But this law cannot be expressed in terms of physics. It is a matter of physiology of which we are at present, and in all probability, always will be, in complete ignorance.

6. There are a great many combinations of physically different kinds of light which are physiologically equivalent in arousing a visual sensation of one and the same color-tone.

From the experimental work which we have accomplished so far it is obvious that a chromatic color-sensation cannot be defined by simply correlating it with a definite kind of monochromatic light. But it is equally impossible to do so by correlating it with a definite combination of colored lights. For there are many such combinations which, though physically different from one another, are physiologically equivalent in arousing a visual sensation of one and the same color-tone. Hence we must next consider the laws which govern the combinations of colored lights, known as the laws of color-mixture. It is by an experi-

mental verification of these laws that the above empirical rule is proved (cf. Helmholtz, Phys. Opt., pp. 311 sqq.).

7. **The first law of color-mixture is that of complementary or antagonistic colors,** which has been explained and proved in the preceding chapter. Though the law deals principally with the origin of the sensations of neutral white and grey, it refers also to chromatic color-sensations. For two colored lights are complementary to each other only, if their relative strength be appropriately regulated. If this is not done, their combination will result in the sensation of an unsaturated color, whose tone approaches that of the stronger component.

8. **The second law of color-mixture is that of intermediate colors, namely: The combination of two colored lights which are not complementary to each other arouses the sensation of an intermediate color. The tone of the latter varies with the relative strengh of the two lights. Its saturation varies from one combination to another and from one experimental condition to another and cannot, as yet, be expressed with accuracy by any universally valid formula.**

The meaning of this law is best understood in connection with the color-triangle, which is a diagrammatic representation of the laws of color-mixture. The spectral and extra-spectral color-tones are so arranged along the sides of the color-triangle that complementary colors lie at opposite ends of any straight line drawn through the "central" point W. Such are, for instance, red and bluish green. All colors which lie too near together to be connected by a straight line through W, are not complementary to each other. Thus green lies too near to red in one direction, blue too near in the other direction. Neither of the two colors is complementary to red.

When we combine two colored lights, monochromatic or mixed, which are not complementary to each other, the result may be compared to weighting the two ends of a lever and finding the centre of gravity. The latter will

lie somewhere between the two ends of the lever and will shift more towards one end or the other, according as we increase the weight at one end or the other. In terms of the law: the result of such a combination is a color-sensation of an intermediate color-tone and the latter will vary with the relative strength of the two component lights (cf. Helmholtz, l. c., pp. 320 sqq.).

An "intermediate color", then, as understood in the second law of color-mixture, has a purely diagrammatic meaning. It is simply a color which in the color-triangle is represented as lying between two non-complementary colors. This and nothing else is signified by the term. Thus, for instance, orange, yellow, and yellowish green are intermediate colors between red and green; carmine, purple, violet, and indigo are intermediates between red and blue.

From this it will be seen that intermediate colors in this diagrammatic sense do not necessarily coincide with intermediate colors, as defined in the second chapter for the purpose of a purely psychological classification of colors. Thus yellow is an intermediate color between red and green in the former sense but not in the latter. For it cannot be said that yellow has similarity with either red or green. Only when we combine the colors which are situated at two adjacent corners of the "color-*square*", do we get "intermediate" colors in both senses of the term.

The sensation of one and the same intermediate color can thus be produced by a great variety of physically different mixtures, though not always in the same degree of saturation. It is frequently stated that the saturation varies with the nearness or remoteness of the two colors which enter into the mixture. That is, the further apart two colors are marked on the sides of the color-triangle, the more unsaturated is the color which results from their combination. This statement, however, is far from being universally true. It is at best a practical guide in experiments with the color-wheel. Even here it is true only when the two colored sectors of the disk are of approximately

the same size. In other methods of color-mixture and especially when monochromatic lights are combined, the matter is very complicated (cf. Baldwin, Dict., pp. 196 and 789 sq.).

Experiment 38. Materials, needed for Exp. 38-41: The color-wheel; a set of color-disks with radial slits; smaller disks without radial slits; a protractor.

In three series of experiments obtain the principal intermediates between the colors situated at the corners of the color-triangle.

(a) Make a compound disk with red and green sectors in the proportion of 330° of red to 30° of green. Note the intermediate color resulting from the rapid rotation of this disk. Then in successive trials increase the green sector to 60, 90, 120, 150, 180, 210, 240, 270, 300 and 330 degrees. We thus obtain some of the numerous intermediates between red and green. Note the vast difference in their saturation. Yellow, thus produced, is so unsaturated as to approach grey.

(b) Obtain in a similar manner the principal intermediates between green and violet. Note again the difference in their saturation.

(c) Proceed likewise to get the principal intermediates between violet and red. Note that their saturation is fairly uniform throughout.

Experiment 39. In a series of four experiments obtain the principal intermediates between the colors situated at the corners of the color-square, that is between (1) red and yellow, (2) yellow and green, (3) green and blue, (4) blue and red. In varying the relative size of the sectors proceed as directed in Experiment 38. Note that all the intermediates obtained are fairly evenly saturated. The extra-spectral color-tones, however, which we get by combining red with blue are less saturated than those resulting from the combination of red and violet.

Experiment 40. Produce in a similar manner the principal intermediates between (1) red and yellowish green,

(2) orange and green. Note that the saturation of the resulting color-sensations is more uniform than was the case when we combined red with green.

Experiment 41. (a) Make a compound disk with orange and carmine sectors and in front of the compound disk (or, preferably on another color-wheel) fasten a small red disk (without a radial slit). Vary the proportions of the two sectors until a red appears which most closely resembles that of the small disk. Note that the saturation of the two reds differs considerably.

(b) Proceed in a similar manner to get the closest approach to the green of a small disk by combining larger disks, exhibiting yellowish green and greenish blue respectively.

(c) Try similarly to combine blue and purple in such proportions that the resulting color will resemble the violet of a smaller disk. Note that the difference in the saturation is not so great as in the preceding two trials (a) and (b).

9. **The sensation of every color-tone (and that of neutral white or grey as well) can be aroused by the combination in different proportions of three colored lights, provided the latter be so chosen that the complementary of any one of them lies between the other two. Red, green, and blue-violet lights have been found by experiment to be the most satisfactory triad of this kind and hence are often referred to as (physical) "primaries".**

This empirical rule states but in another form what we have ascertained experimentally, when proving the second law of color-mixture. For we found in Experiment 38 that by the appropriate combination of the colors situated at the corners of the color-triangle, all their intermediates can be obtained. The colored lights which cause the sensations of these three colors respectively are precisely such as are described in the present empirical rule. That also the sensation of white or grey can be obtained by the same triad of lights we established in Experiment 20 (a).

There are many other triads of colored lights which answer the same description and may be employed for the same purpose. We found, however, (in Exp. 38-41) that the saturation of the intermediate colors, thus obtained, differs considerably from one combination to another. Hence not all triads are equally available, if we desire colors of a relatively high degree of saturation. The combination which has been found by experiment to be the most satisfactory in this regard is that of red, green, and blue-violet lights. It is for this reason that red, green, and blue-violet, are frequently referred to as ''primary colors''.

It must be emphasized that the term ''primary colors'', as applied to these three colors, has a very different meaning from the same term as applied to the four colors situated at the corners of the color-square. When we call the latter ''primaries'', we express nothing but a plain fact which can be ascertained by introspection. We have explained this, when dealing with the purely psychological classification of chromatic color-sensations. Hence red, yellow, green and blue are not physical, but psychological primaries. The above three colors, on the other hand, are not psychological, but physical primaries; that is: Any three kinds of light which cause the sensations of these three colors respectively, can also produce in appropriate combination the sensations of all other color-tones. Hence the tone of every chromatic color-sensation, no matter by what physical light it is actually produced, can be expressed in terms of red, green, and blue-violet; that is: All other color-tones can be treated as if they were ''derived'' from red, green, and blue-violet lights. Here, however, we must remain aware of two facts, lest we overstate the case. The first is that the only reason why we call the colors of this triad ''physical primaries'' in preference to those of many other triads is a purely practical one: they are the most satisfactory primaries. The second is that when we speak of ''red, green, and blue-violet lights'' a great many physically different kinds of light may be designated by

these terms and may be employed for the same practical purpose.

It is important to note all this, because one of the two best-known theories of color-vision starts out from the facts designated by the term "three physical primaries," the other from those expressed by the term "four psychological primaries." We shall discuss the relative merits of these two rival theories in another chapter.

A practical demonstration of the three "physical primaries", here discussed, is afforded by examining a Lumiere "autochrome" plate, that is, a transparency, made by the Lumiere process of three-color-photography. We are not concerned here with the technique of the photographic process itself but only with the finished product. If such an autochrome be viewed in transmitted light, by holding it against the brightly illuminated sky, or better still, by placing one of lantern-slide size in the carrier of a stereopticon, the objects photographed will appear in their natural colors. At least this effect is approximated to a remarkable degree. In this instance all our color-sensations, including those of white and grey, are due to the combination in different proportions of red, green, and blue-violet lights. What adds to the interest of this demonstration, is the ingenious method of effecting the physical mixture of these three kinds of light. As substantially the same method of color-mixture is also used for other artistic purposes, as for instance, in tapestry and that form of painting which is known as "pointilistic", it shall be briefly explained here.

Lumiere autochrome plates are provided with a layer of minute starch grains, dyed red, green, and blue-violet, and in the proportion of four green to three red and two blue. On every inch of the plate there are about four millions of these grains, not superimposed upon one another, but in juxtaposition. When the photograph is taken, light must first pass through this "color-filter", before it reaches the sensitive film, and when the finished picture is projected

on a screen by means of a stereopticon, light is similarly filtered, before it reaches the screen. Hence only red, green, and blue-violet lights reach the eye, when we look at such a screen(cf. G. L. Johnson, Photography in Colours, ed. 2, pp. 84 sq.).

An observer near the screen, say about two or three feet away from it, can see the magnified images of the starch-grains clearly. Those who are about ten feet away from the screen can no longer distinguish the juxtaposed colored spots. They see instead the objects photographed in their natural colors.

The reason for this is that the human eye is unable to focus such small objects as these colored spots separately, when they are viewed beyond a certain distance. It is as if we tried to read very small print at such a distance: all letters would look blurred. In technical language this is expressed by saying that the juxtaposed colored spots on the screen cause "circles of diffusion" on the retina; that is: They stimulate each a wider area of the retina than is consistent with their distinct vision. The circles of diffusion, caused by neighboring colored spots on the screen, must necessarily overlap on the retina. Now this means that the same retinal elements are stimulated simultaneously by different colored lights. It is owing to the ingenious method, employed in making these photographic transparencies, that the three "primary" lights, red, green, and blue-violet, reach the retina in different proportions, according as we look at one portion of the screen or another. Hence it is that a white object, thus photographed, looks white, a golden one golden, and so forth.

10. What is true of the tone of a color-sensation, holds likewise of its brightness and saturation: they depend indeed on the nature of the physical stimulus but cannot be defined thereby. In particular it is far from being universally true that the brightness of a chromatic color-sensation depends solely on the amplitude (or energy) of the light-wave, and its saturation solely

on the form of the wave (that is, on the relative purity of the latter from admixture with waves of different lengths).

Before we begin to correlate the brightness and the saturation of a color-sensation with the properties of its physical stimulus, we must recall the purely psychological meaning of the terms brightness and saturation. As we explained in the second chapter, by the brightness of a color we simply mean its relative similarity with white; by its saturation we designate the relative clearness of its tone, so that it cannot be confounded with either white, grey, or black. The darker, for instance, a red is, the less similar it is to white, and the less clear, too, its color-tone. A dark red, then, is a color of a low degree of both brightness and saturation. A very whitish red, on the other hand, is a color of a high degree of brightness, but a low degree of saturation.

Within certain limits it is true that the brightness of a definite color increases or decreases, as we increase or decrease the intensity (or energy) of the colored light which causes the sensation. This fact we can readily ascertain by viewing a piece of red paper first in diffused, then in direct sunlight, and then casting a deep shadow on it. In all three cases it is the intensity of the colored light which is changed, and the brightness of the color changes likewise. But it is not true that we thus change only the brightness of the color; we change its saturation as well. Under appropriate conditions even its tone may thus be changed or completely neutralised. For as we have seen in chapter III, any colored light, sufficiently increased in intensity, causes the sensation of neutral white. Before, however, this intensity is reached, many colored lights undergo a change of tone.

Similarly it is true that by changing the form of a light-wave (that is, by mixing one colored light with another) we can produce a color-sensation of a low degree of saturation. But apart from the fact that this is not universally true, especially when monochromatic lights are mixed, the

very laws of color-mixture show that by changing the form of the wave we change also the tone of the sensation or neutralise it entirely.

We can also change the saturation of a color-sensation without changing its tone by mixing a definite colored light with (any kind of) white light in varying proportions. But this again is not universally true. For here the law of the threshold of color-sensation comes into play, as we have explained in the third chapter (pp. 70 sqq.). We found moreover that this threshold differs from one color to another (Experiment 29). The simple fact is that the human retina is not equally sensitive to all colored lights. Just as there are constituents of sunlight (namely its infra-red and ultra-violet rays) to which the human eye is not attuned at all, so too the eye is not equally attuned to the various portions of the visible spectrum. It is this important fact which is completely ignored when attempts are made to define the three attributes of a color-sensation in purely physical terms.

Brightness-determinations of colored lights have of recent years become a problem which is no longer of merely academic interest, but its correct solution is valued in terms of dollars and cents. Illuminating engineers are most intensely interested in this problem. We have pointed out already in the second chapter how difficult psychological determinations of the relative brightness of different colors are. Hence everything that human ingenuity can devise has been tried to eliminate this difficult portion of the problem and to determine the brightness of colored lights by "purely objective methods." Now if there is anything on which illuminating engineers agree as a result of extensive experience in this regard, it is this: The brightness of a colored light is one thing, and its physical intensity or energy is quite another. The former cannot be determined solely in terms of the latter.

Experiment 42. Materials: A direct-vision spectroscope.

Hold the direct-vision spectroscope against the brightly illuminated sky and make the slit of the instrument so narrow that you can see the Fraunhofer lines clearly. Compare the various colors of the spectrum as to their brightness and saturation. There are certain differences in this regard which even a beginner in experimental work cannot fail to notice. The two ends of the spectrum are evidently very dark. That is, the extreme red and violet portions of the spectrum are of a very low degree of both brightness and saturation. Yellow, on the other hand, is plainly the brightest and least saturated of all spectral colors. It forms a very narrow band, clearly marked off from the red end by a black absorption line. If the observer does not see this plainly, then either the slit is not narrow enough or the convex lens in the spectroscope is not accurately focussed on it. Practiced observers will detect many other differences in the brightness and the saturation of the various spectral hues. But those mentioned will suffice for the purposes of our present experiment.

Now note first of all that the differences in the saturation of the various spectral colors cannot possibly be due to differences in the form of the waves which cause the various sensations. For by narrowing the slit, as directed, we get the closest approach to monochromatic lights possible, that is, all waves are as pure from admixture with others, as they can be.

Note secondly that the relative brightness of the spectral hues is not due to the relative intensity or energy of the various wave-lengths. The latter has been measured with great accuracy by physicists. It would lead us too far afield to explain here the methods employed in these delicate measurements or to record the details of the results obtained. Texts of physics (as for instance, Watson, pp. 554 sqq.) will supply the information. This, however, can be stated without qualification that these energy-determinations do not correspond at all with the obvious results of our present experiment nor with the more delicate bright-

ness-determinations, made in the psychological laboratory by experienced observers.

Experiment 43. Now widen the slit of the spectroscope and note that, in proportion as we do so, the saturation of the colors observed is increased. The immediate result of widening the slit is that the amount of light which passes through the slit is increased. As a further result, however, numerous spectra are made to overlap, as we explained above (p. 81). In other words, by widening the slit we decrease the purity of the waves which produce the various color-sensations. In spite of that the saturation of the colors is not decreased but increased. In the present instance this increase is evidently due to the increase in the intensity (or energy) of the light. Plainly, then, the saturation of a color-sensation does not depend solely on the purity of the wave.

Experiment 44. Perform Experiment 37 over again and note two things, namely, (1) the high degree of saturation of the colored fringes, and (2) the fact that these fringes are due to multiple mixtures of different kinds of light. (See p. 81.)

The most saturated colors which we observe in nature are those of the rainbow. They are likewise due to multiple mixtures of different kinds of monochromatic light, namely, to the overlapping of many different spectra. It does not lie within the scope of the present chapter to explain how this overlapping of spectra is brought about in the case of the rainbow. Text-books of physics should be consulted.

11. Conclusion. The result of our experimental inquiry into the physical conditions of chromatic color-sensations can be briefly stated as follows. The three attributes of normal color-sensations depend undoubtedly on the nature of their physical stimuli, and in particular on the length, amplitude, and form of light-waves, but the former cannot be defined by the latter. By simply examining the said

three properties of any particular light-wave we get as little information as to why it arouses a color-sensation of this tone, and this degree of saturation and brightness, as we get with regard to the problem why the great bulk of sunlight, namely, its infra-red and ultra-violet rays, cause no visual sensations at all. Neither of these two problems can be answered in purely physical terms. Both are primarily questions of the sensitivity of the eye. Consequently any theory of color-vision which purports to explain the tone, the brightness, and the saturation of color-sensations by simply correlating them with definite properties of light, must be ruled out.

CHAPTER V

THE PHENOMENA OF CONTRAST AND ADAPTATION, AND THE SENSATION OF BLACK

1. The Task before Us. We said in the second chapter that the sensation of any color-tone in nature can, under appropriate conditions, be produced by what the physicist calls "white light." The appropriate conditions referred to, are those of contrast. The modifications which are brought about by them in the effect of "white light" are some of the most striking phenomena of contrast, but by no means the only ones. For the very conditions which modify the effect of "white light" modify in some way or other also the effect of every other light. We have so far studiously avoided these conditions, or rather, reduced them to a minimum, but now we shall create them artificially in order to verify experimentally their modifying influence upon all our color-sensations.

The phenomena of contrast are so intimately connected with those of adaptation that the discussion of the latter follows most naturally upon that of the former.

The sensation of black plays a rather important role in our everyday experience. Hence the reader may be greatly surprised to see it here coupled with phenomena which are frequently referred to as "abnormal". There is no doubt a grain of truth in the statement that the phenomena of contrast are "abnormal". The conditions for observing the more obtrusive phenomena of this kind are rarely realized in our everyday experience and must be artificially created in the laboratory. If this be meant by the term "abnormal", then and in so far, the phenomena of contrast are abnormal. The reader should, however, be on his guard not to exaggerate their "abnormality." For the experimental work of this chapter will show that the sensation of

black is in every instance a phenomenon of contrast and, what is more, it is of all contrast effects, the most unique. In the case of all other contrast phenomena we are dealing with the modifying influence of one stimulus upon the effect of another. In the case of the sensation of black we are dealing with the production of a positive sensation in the absence of a physical stimulus, and due entirely to the presence of other stimuli, causing other sensations.

To put the matter in a more concrete form: Surely the reader would not agree to the statement that his ability to read the print of this page is in any sense of the term an "abnormal" phenomenon. It is, however, due exclusively to contrast, provided the letters of the print are really in that condition which the physicist describes as black, that is, provided the letters themselves present no physical stimulus to the eye at all. When he looks directly at any particular letter, then the area of clearest vision in the retina is completely shielded from all physical stimulation. If it were not for the fact that the rest of the page, to which he does not pay any attention at all, stimulates the other portions of the retina, he would not be able to read the print. Moreover, in proportion as the letters themselves approach the "normal" condition of bodies in nature, that is, in proportion as they reflect any light at all, the contrast diminishes and in the same proportion the legibility of the print decreases likewise.

2. Simultaneous Contrast. When we look at one colored object, say a piece of red paper, there are usually numerous other objects in its neighborhood which act simultaneously on the eye. In other words, while one portion of the retina —the area of clearest vision—is affected by one kind of light, the other portions of it are affected by different kinds of light. When the object looked at is a black one, then the area of clearest vision is completely shielded from all physical stimulation, but the other portions of the retina are acted upon by light from other objects. As the different portions of the retina are really only so many parts

of one and the same organ of vision, it is natural to expect that the disturbance set up in one portion, or the complete physiological rest afforded to it, should influence the physiological condition of the other portions, and consequently also our color-sensations. And so it is. Now these physical and physiological conditions are known by the name of simultaneous contrast and the modifications in our color-sensations, resulting from them, are the phenomena of simultaneous contrast.

3. The Threshold of Contrast. The phenomena of simultaneous contrast are very numerous and complex. In general they consist in a change of brightness, or saturation, or color-tone; or in this, that a neutral color is changed into a chromatic one, or vice versa, a chromatic color into a neutral one. Which of these various effects will take place, depends of course primarily on their physical and physiological conditions, but to some extent also on the psychological condition of the observer, that is, on the direction of his attention.

A neutral color may be contrasted with a chromatic one, or the colors contrasted may be both neutral or both chromatic. In the latter case they may differ in brightness, saturation, or color-tone. The colored surfaces may lie near together or far apart, that is, they may affect adjacent portions of the retina or such as are widely separated from each other. Their differences may be slight or considerable. Several such differences may be simultaneously present and interfere with one another or one of them may be so prominent as to exclude practically all others. To complicate matters still further, conditions may also be present which favor contrast-effects of a different order, namely those which we shall discuss under the heading of successive contrast, and the latter may help or hinder those of simultaneous contrast. And last, but not least, we may attend to such differences or we may ignore them more or less completely.

From this it will be seen that the phenomena of simul-

taneous contrast—and the same is true of successive contrasts—are something of a tangle which can be unravelled only under laboratory conditions. Hence the fact that in our ordinary experience most contrast-effects pass unnoticed. This does not mean that they are not present. We can never eliminate their physical and physiological conditions entirely. Hence we are really never without contrast-effects of one kind or another. But many of them are so slight that they lie outside the sphere of our attention. In other words, what we said in the third chapter concerning the threshold of sensation in general, the differential threshold, and the threshold of color-sensation in particular, applies also to the phenomena of simultaneous contrast: there is also a threshold of contrast.

4. Some Empirical Rules concerning Simultaneous Contrasts. Even under laboratory conditions it is very difficult to obtain pure contrast-effects of a definite kind. For the law of the threshold applies also there. The following empirical rules express the conditions which are most favorable for forcing simultaneous contrast-effects on our attention and the modifications of our color-sensations which we then observe.

(1) If the contrasting colors differ mainly in brightness, then the darker color will look still darker and the brighter one still brighter. This is known as *brightness-contrast,* of which the sensation of black is only a special case.

(2) Grey, contrasted with any one of the chromatic colors, will change into the complementary of the latter, especially if all brightness contrast is avoided. This is the *most remarkable form of color-contrast.*

(3) Complementary colors enhance each other. If two non-complementary colors are contrasted, each will change the tone of the other and this change lies in the direction of the complementary color of that other. This is *another form of color-contrast.*

(4) The nearer together the contrasting colored surfaces

are, the more noticeable will be the contrast-effect. This is known as *marginal contrast.*

Experiment 45. (Colored shadows.) Materials: Two incandescent lamps (without shades or reflectors), one white (W), the other colored, say red (R); electrical connections which make it possible to move the ordinary white lamp independently of the other; a large piece of white paper to serve as as screen; a pencil. Colored lamps, used for stage illumination, will serve the purposes of this and the following experiments excellently.

Place the sheet of white paper (abcd) flat on a table and set up the two lamps as indicated in Fig. 18. Then hold a pencil (P) vertically over the white paper and note that the pencil casts two shadows. The one, marked r, will look red, the other, marked w, will be bluish-green. If the latter is rather whitish, move the white lamp backwards in the direction of the arrow until both shadows look most saturated. Mark the position of the white lamp, where this occurs.

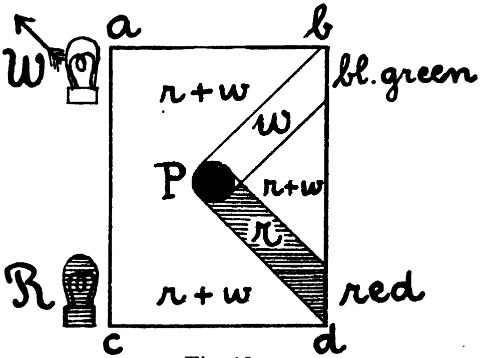


Fig. 18.

Note carefully the conditions under which the two shadows looked colored and most saturated. Space r is illuminated only by red light, the white light being obstructed by the pencil. Space w is illuminated only by a faint white light, the red light being obstructed by the pencil. The spaces, surrounding the two shadows, are

illuminated by both lights, that is, by a whitish-red light ($r + w$). It is owing to the contrast with its whitish-red surrounding that space w assumes the color-tone complementary to red, namely bluish-green.

Note secondly the changes in the saturation of the greenish-blue shadow which occur, when an assistant moves the white lamp nearer the pencil and then further and further away from it in the direction of the arrow. When the lamp is brought nearer, the brightness of its illumination is increased and when it is moved further away, its brightness is reduced. In the first case the bluish-green shadow looks more and more whitish and may disappear entirely; in the second the saturation of its color increases, reaches the maximum attainable under the circumstances, and then decreases again, the shadow now becoming darker and darker. When the saturation of the bluish-green color-tone is at its best, the illumination of the two lamps is, roughly speaking, equal in brightness and then all brightness-contrast is eliminated.

Note thirdly that the saturation of the red shadow also changes when the position of white lamp is changed. The more whitish the green shadow becomes, the more darkish will be the red one and vice versa. When the green shadow is at its best, the red shadow is likewise. (The latter statement is at least approximately true.) All these changes in the red shadow occur in spite of the fact that space r is always illuminated by the same unchanging light. For the red lamp is supposed to be stationary. Hence the identical red light, reflected from the identical surface and reaching the eye in the same intensity (the observer is supposed to remain in the same position) causes now the sensation of a relatively saturated red, now that of a whitish red, now that of a blackish-red, now practically that of white, now that of a neutral dark grey. The only thing which is changed is the illumination of the surfaces surrounding the red shadow. Hence all these changes in the color of the shadow are due exclusively to contrast.

The colored shadows and all their changes described

appear even better, if the white screen (abcd) is not put flat on the table, but is set up vertically over against the two lamps at a suitable distance. The pencil then should be held very near, and parallel with, the screen. *This experimental arrangement should be used. The former was only described, because it makes the diagrammatic representation of the physical conditions of the experiment easier.*

It need not be stated explicitly that this and the following experiments (45-51) must be made in a completely darkened room. For otherwise there is a third light (namely diffused sunlight) which interferes considerably with the contrast-effects described.

Experiment 46. (Colored shadows.) We proceed exactly as in experiment 45, except that we use now a green lamp instead of a red one. Note that shadow w now is carmine-red.

We use next a blue lamp, and note that w now looks orange-yellow.

As a result of experiments 45 and 46 we have, then, the notable fact that the same space of white paper, illuminated by the identical white light, looks now greenish-blue, now carmine-red, now orange-yellow. It is only the illumination of the surfaces, surrounding w, which is changed when we change the colored lamps. Hence the color of w is due exclusively to contrast. We can make the same space w look any color whatever, provided we have enough colored lamps for changing the illumination of the contrasting surfaces.

Experiment 47. Materials: the same as in experiment 45. When the two colored shadows are at their best, eliminate the white light. This may be done sufficiently by holding a book (bb′ in Fig. 19) in front of the white lamp. Note that the bluish-green shadow becomes black and the red one disappears entirely.

Though space r is illuminated by the same identical red light as in Experiment 45, it is now rather whitish and

indistinguishable from its surrounding spaces. There is no contrast. For the surrounding spaces are now illuminated by the identical red light. The latter is rather faint and may be little above the threshold of color-sensation or entirely below it. Now take the book away again and note the remarkable change in the saturation of r. The surrounding spaces are again illuminated by r + w. Hence it is entirely due to the presence or absence of contrast that the identical surface, illuminated by the identical light, and seen from the same distance, now looks whitish red or whitish grey, now saturated red.

Space —w looks black, because it is not illuminated at all when the white lamp is eliminated. This will be the

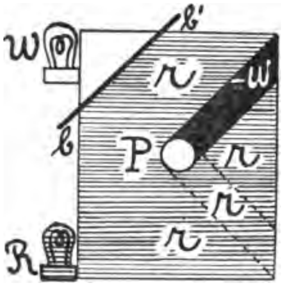


Fig. 19.

case, even if the surrounding surfaces are above the color-threshold, that is, if they look noticeably reddish. Hence note the fact that the sensation of black arises not only by contrast with white, but with any colored surface whatever, provided from some portion of the latter all illumination is eliminated. The brighter, however, the illumination of the surrounding surfaces is, the blacker will be the shadow and thus the contrast between black and white is greatest.

We have noted already in the second chapter that black is not an unvarying phenomenon in our everyday experience and language. At noon-time when all objects around us are flooded with direct sunlight, a tree casts what we call a black shadow on a green meadow. If we

were to watch carefully and describe our sensory experience accurately, we ought to say rather that the shadow is dark green. For the grass in the shadow is illuminated by some diffused sunlight. If, however, the meadow is sufficiently far away, the dark-green color of the shadow may be below the threshold of color-sensation and thus become very deep grey. This means in our everyday language: it is black.

Experiment 48. We proceed as in Experiment 45, except that we use now two white lamps, W and W′ in Fig. 20. Space w is illuminated only by W; space w′ only by W′.

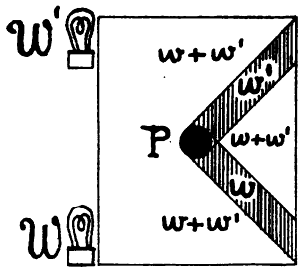


Fig. 20.

The surrounding spaces (w+w′) are illuminated by both lamps. Hence by contrast w and w′ look grey.

We now elimnate W. Space —w (in Fig. 21) is not illuminated at all and looks black.

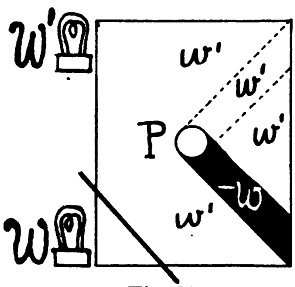


Fig. 21.

Space w′ is illuminated by the identical light as in Fig. 20, namely by W′ and still it does not look grey as it did before. For now the surrounding surfaces are also illu-

minated by the same light W′. It is thus owing to presence or absence of contrast that the same surface, illuminated by the same white light, looks now dark grey, now light grey.

Experiment 49. Note the changes in color-tone which occur, when two non-complementary colors are contrasted.

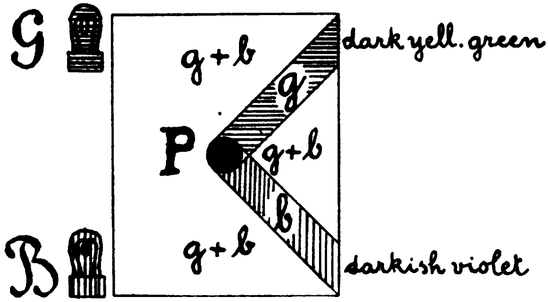


Fig. 22.

The experimental arrangement is the same as in Experiment 45, except that we now use two colored lamps, one green, the other blue.

Though g in Fig. 22 is illuminated exclusively by green light, it does not look green but its color is changed to dark yellowish green. Similarly b, though illuminated only by blue light, now looks violet and is rather dark. This is due to contrast with the surrounding surfaces which are illuminated by both lamps, that is by greenish-blue light (g+b).

Experiment 50. Try the combination of a green lamp with a red one. Note that g (in Fig. 23), illuminated by the same green light as in the preceding experiment, now looks slightly-bluish green. Red light, reflected from r, now causes the sensation of orange-red or vermilion. Both colored shadows are highly saturated, if the distance between the two lamps is properly adjusted. The surfaces, surrounding the two shadows are noticeably yellow. For they are illuminated by a mixture of red and green lights

(r+g). The changes in the tone of the colored shadows are due to their yellowish surrounding.

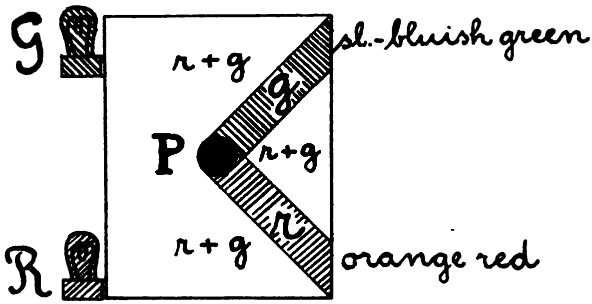


Fig. 23.

Experiment 51. Combine a red lamp with a blue one. Note that blue light, illuminating b (in Fig. 24), now causes the sensation of a slightly-greenish blue, and red light, illuminating r, the sensation of orange-red or vermilion. The spaces, surrounding the two shadows, are illuminated by a mixture of red and blue lights (r+b), that is by purplish light.

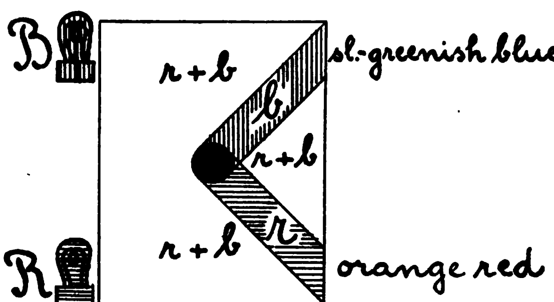


Fig. 24.

In a similar manner other colored lamps may be combined. But the combinations used are sufficient to show the remarkable changes in color-tone which result from contrasting non-complementary colors. If we now ask ourselves, by what law these changes of color-tone are governed, we find the following. It is indeed impossible

to foretell with precision which tone any particular shadow will have, because we cannot control sufficiently the strength of the two colored lights. (The above statements concerning the colors of the various shadows are actual records, which, however, will be approximately true when other light-sources of the same color are used.) But we can, at least, indicate with precision in what direction the tone of any shadow will change, namely: in the direction of the color which is complementary to the background. In a more concrete form: *Any colored shadow which arises under these conditions of color-contrast has always that tone which would arise (independently of contrast), if the colored light which it actually reflects were mixed with the complementary of the background.*

Thus shadow g (in Experiment 49, Fig. 22) reflects actually green light and its background greenish-blue light (g+b). The complementary of greenish-blue is red. Now red, if mixed with green, will, according to the relative strength of the two lights, yield the sensation of any color-tone between red and green. Among these is also yellowish-green. The student should be in a position to work out for himself, how the same empirical rule applies to all the other shadows obtained in the last three experiments.

Experiment 52. (A substitute for Exp. 45). Materials: A plane mirror; a piece of red glass; a dull-black pencil.

A simpler experimental arrangement for observing colored shadows is the following. On an ordinary plane mirror place a piece of red glass. The latter will act as an additional mirror. With his face turned away from the window the observer holds the two mirrors at reading distance in such a way that the white clouds are reflected in them. The white clouds will look reddish. For the diffused sunlight, coming from the clouds will have to pass through the red glass, before reaching the silvered mirror and, on being reflected to the eye, it will have to pass through the red glass a second time, being filtered thereby. But besides this, the same diffused sunlight will also be

reflected from the top-surface of the red glass. This reflection is rather weak, but the light is unfiltered, that is, it is faint white light. Hence the whitish-red image of the white clouds. In the accompanying diagram (Fig. 25) the image of the white clouds is marked r+w.

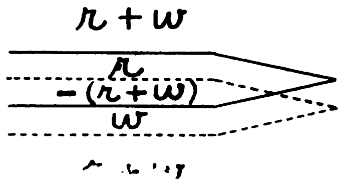


Fig. 25.

Now hold a (dull-black) pencil before the two mirrors. Under these conditions the pencil will not throw any additional light on the mirrors, that is, it will not be imaged in them like the white clouds. On the contrary it will eliminate some of the light coming from the clouds, that is, it will cast a shadow, or rather two shadows. On the top-surface of the red glass it will cut out a portion of the unfiltered white light reflected from that surface. This first shadow is indicated in the accompanying diagram by dotted lines. On the silvered surface of the lower mirror the pencil will cut out a similar portion of the red light reflected from that surface. This second shadow is indicated in the diagram by the unbroken lines. When the pencil is held near the two mirrors, these two shadows will be partially overlapping. Hence from the portion, marked r, only red light will reach the eye, from that marked w only faint white light, from the overlapping portion, marked—(r+w), no light at all. The latter portion will look black; r will be red; w will not look white or grey but, by contrast with its surrounding (r+w), will appear in the color complementary to red, that is, it will have a tinge of bluish-green (cf. Sanford, A Course in Exp.. Psych., pp. 156 sq.).

Experiment 53. (A substitute for Exp. 46.) We proceed exactly as in the preceding experiment, except that

we now use a piece of blue glass. Note that w, illuminated by the same white light as before, has now a tinge of yellow.

By using successively glasses of still other colors we change the illumination of the surfaces which surround w. The latter, though illuminated in every case by the same faint white light, assumes successively different colors.

Experiment 54. (Veil-contrast.) Materials: A piece of black velvet (or dull-black paper) and a sheet of white baryta paper; two pieces of white tissue paper of the same size as the latter; two strips of medium grey paper, cut from the same sheet and hence identical in brightness, each about a quarter of an inch wide and two inches long.

The following is known as Meyer's experiment. Place the piece of black velvet (or dull-black paper) and the sheet of white baryta paper side by side. Put one of the grey strips on the former, the other on the latter. Cover both with tissue paper and press this down at its edges. Note that the same grey paper looks whitish on black velvet and rather blackish on white baryta paper. Interchange the two strips and note the result (cf. Sanford, l. c.).

Experiment 55. Materials: A set of colored papers: yellow and blue, red and green, and so forth; tissue papers; strips of the same medium grey paper.

Proceed as in the preceding experiment and note that grey becomes tinged with blue on a yellow background, with yellow on a blue background, with bluish-green on a red background, and so forth.

Experiment 56. Materials: The color-wheel. A large dull-black disk and a small one, both cut from the same sheet; two similar white disks; a medium grey disk, whose diameter should be about half an inch larger than that of the small disks; a large disk, made of white tissue paper. The grey disk and the two small disks should be accurately cut and centred.

Mount the large black disk (1 in Fig. 26) on the color-

wheel arbor, then the grey one (2), and on this the small black disk (3). Cover the whole with the white tissue-paper disk. When we set this combination in rapid rotation, there will be a narrow grey ring (2) on a blackish background (1 and 3). Note that the grey ring looks rather whitish.

Fig. 26.

Now substitute the two white disks for the two black ones, proceeding for the rest as before. Note that the same grey ring now looks rather darkish.

Experiment 57. Materials: Large and small colored disks, yellow, blue, red, green, and so forth; the same grey disk, used in the preceding experiment; the same tissue paper disk.

Proceed as in Experiment 56 and note that the same grey ring has a tinge of bluish-green on a red background, of yellow on a blue background, of carmine-red on a green background, and so forth.

Experiment 58. Materials: The same as in Experiment 57, except that instead of the plain grey disk we use now any one of the disks described in the subsequent text.

In the experiments of the third chapter we found that compound disks with two, three, four, five, or any number of colored sectors, are "equivalently grey", that is, arouse the sensation of grey, if their colored sectors are appropriately chosen and adjusted, and their rotation is sufficiently rapid. Suppose we find among our records the following color-equations:

1) $170°\ Y + 190°\ B =$ neutral grey.

2) 110° R + 128° G + 122° V = neutral grey.

3) 93° G + 87° P + 85° Y + 95° B = neutral grey.

4) 85° Y + 95° B + 55° R + 64° G + 61° V = neutral grey.

We proceed exactly, as in experiments 56 and 57, except that we substitute any one of these "equivalent grey" disks—say the second one—for the plain grey disk. We have now a contrast-ring which consists of three colored segments, red, green, and blue respectively. Note that this ring looks uniformly yellowish on a blue background (Fig. 27), uniformly bluish on a yellow background, and so forth. It will appear more whitish or darkish than it does when rotated alone, according as we place it on a darkish or whitish background. It should be added, however, that,

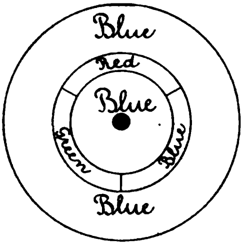


Fig. 27.

when colored backgrounds are used, brightness-contrast may interfere considerably with color-contrast.

The instruction which we gave above about the size and accurate centring of the grey disk should be carefully observed. Else complications will arise which modify or destroy altogether the contrast-effects described.

5. **Successive Contrast.** We have seen in the preliminary experiments of the first chapter that the physiological change which is produced in the retina by the action of light, persists for some time after the withdrawal of the latter, and, under favorable conditions, considerably. It stands to reason, then, that the effect of any particular light on a definite retinal area should be modified by the effect which its predecessor had on the same retinal area.

If this is correct, then one and the same colored object should look somewhat different—possibly very much different—according as this or that other colored object has been viewed previously. And so it is. The changes in the appearance of a colored object which are due to the fact that the same retinal area has been previously stimulated by light from another colored object are known as the phenomena of successive contrast. Though of constant occurrence, most of them are so slight that they pass unnoticed. The conditions which are most favorable for forcing them on our attention will become clear from the following experiments (cf. Seashore, Elem. Exp. in Psych., pp. 1 sqq.).

Experiment 59. Take a small piece of red paper, about an inch square, and in the centre of it make an ink-dot to serve as a fixation-point. Put this square on a sheet of white paper. On the latter, and at some distance from the colored square, make another fixation-mark, say a very small cross. Place the sheet of white paper, thus prepared, at reading distance and look with one eye directly at the ink-dot in the centre of the red square. Continue to look at it for about 15 seconds. (We time ourselves by counting slowly from 1 to 15.) Then look just as steadily at the small cross and note the change in the appearance of the white paper which occurs under these conditions. A portion of it, corresponding in size to the red square, will appear bluish-green. It is known as a "negative after-image". Note also the dark appearance of that portion of the white paper which immediately surrounds the bluish-green square and observe the gradual fading of these effects of successive contrast.

The phenomena described may be complicated by simultaneous contrast. We should simply describe what we actually experience and not concern ourselves about what others experience. Not only are there individual differences in color-sensitiveness but a definite change in the resulting sensation may be below the threshold for one and

above it for others. We may have to vary the time of fixating the ink-dot of the red square: 15 seconds may not be enough or they may be too much. We must also take care to fixate the small cross steadily while observing the contrast-square. If we fellow the contours of the latter, it will run away from us so that we have not time enough to observe anything accurately. The purpose of the ink-dot and the small cross is to keep the eye in a steady position. Without such an artificial means few are capable of preventing their eyes from wandering. This is the principal reason why most contrast-effects pass unnoticed in our everyday experience.

Experiment 60. We proceed exactly as in experiment 59, except that we now use other colored squares: green, blue, violet, yellow, purple, and so forth. Note the color of the contrast-square and what relation it bears to that of the original square.

Experiment 61. Use a small black square, marking its centre by making a pin-hole through it. For the rest proceed as in Exp. 59. Note the enhanced brightness of the white contrast-square.

Experiment 62. Make an ink-dot in the centre of a small white square and place the latter on a piece of black paper. Then focus a small cross on a sheet of white paper. Note how dark the contrast-square looks and describe the appearance of its surrounding.

As a result of experiments 59-62 we have, then, the notable fact that the same white light, reflected from the same white paper, and reaching the eye in the same degree of intensity, causes now the sensation of green, now that of carmine, blue, yellow, and so forth, now again that of a dark grey, now that of a rather brilliant white. All this depends exclusively on the physiological condition in which the retina is here and now. This physiological condition depends mainly on the previous stimulation of the same retinal area by some other sort of light; in part also it

depends on the simultaneous stimulation of other portions of the retina.

Experiment 63. We proceed as in experiment 62 except that we project the after-image on a sheet of black paper. It takes an appreciable time before the contrast-effect develops,—and it changes. When it is at its best, a portion of the black paper, corresponding in size to the white square, will look much blacker than it does under ordinary conditions. Note also that the rest of the black paper appears whitish-grey.

These results are due partly to successive, partly to simultaneous contrast and partly to the fact that the black paper is not ideally black in the sense of the physicist. It reflects a very slight amount of white light. This amount, according to the physiological condition of the retina, is now above, now below, the threshold of sensation. We shall return to this in Exp. 67.

Experiment 64. (a) Make an ink-dot in the centre of a small yellow square and a small cross in the centre of a larger blue square. Put the two colored papers at some distance from each other on a sheet of white paper. Focus the ink-dot for 15 seconds, then the cross, and watch carefully the gradual appearance and disappearance of the contrast-effect.

(b) Proceed in the same way, using the following combinations of colored squares:

Small squares:	*Larger squares:*
blue	yellow
yellowish green	violet
violet	yellowish green
purple	green
green	purple
any color	complementary color

In this experiment two complementary lights are successively presented to the same retinal area. The result is that the effect of the second of any such pair is enhanced. Thus the blue contrast-square looks much more saturated

than the rest of the large blue square, after we have focussed the small yellow square. Why should this be so? For we found in the experiments of the third chapter that the successive presentation to the same retinal elements of complementary lights results in the sensation of grey. But the proviso there was that the successive presentation must be very rapid. Then the physiological disturbance created by the two lights is compounded and equivalent to the physical mixture (or simultaneous presentation) of the two lights. In the present experiment the conditions are very different. The eye has been fatigued by yellow light (by the steady focussing of the yellow square) and is in consequence locally blue-sighted. Blue light has now an enhanced effect.

Experiment 65. We proceed exactly as in experiment 64, except that we now use squares whose colors are not complementary to each other. Try the following combinations:

Small squares:	*Larger squares:*
yellow	red
green	yellow
purple	yellow
any color	any non-complementary color.

From the experimental work accomplished so far, we can determine beforehand what the result of such a mode of procedure will be. By looking steadily at the small yellow square, the eye becomes locally blue-sighted, that is, it acquires the same condition as would be ordinarily produced by this complementary light. By looking then at the large red square, red light actually reaches the blue-sighted area of the retina. *The result should be equivalent to that produced by the physical mixture of blue and red lights.* And so it is. For the small contrast square looks purplish red.

Note that the results of this experiment tally with those of experiments 49, 50 and 51. *The same empirical rule holds for successive, as for simultaneous contrast.*

6. Adaptation. When the retina of the eye is acted upon continuously for some time by the same light, its sensitiveness undergoes a gradual change. Colored objects, viewed with the eye in this condition, look different from what they would, otherwise. Something similar occurs when the retina is (more or less completely) shielded from stimulation for a prolonged period of time. The change in the sensitiveness of the retina, which is due to its continued stimulation by the same light, or to the prolonged shielding of the retina from all stimulation, is known as adaptation. The resulting changes in the appearance of colored objects are the phenomena of adaptation.

According as the change of sensitiveness affects the whole retina or only—at least noticeably—a particular portion of it, we distinguish general and local adaptation. We have already become acquainted with the principal effects of the latter. The phenomena of successive contrast were really effects of local adaptation. Thus, for instance, we saw in experiment 64 that the steady focussing of a small yellow square renders the area of clearest vision more sensitive to blue light or ''blue-sighted'', as we expressed it. Hence it is that a white object, looked at immediately thereafter, appears bluish (Exp. 60), a blue object more saturated (Exp. 64), all other colored objects, as if the light which they reflect were mixed with blue light (Exp. 65). We say really nothing new, when we state now explicitly that the same retinal area has become *less sensitive for yellow light*. To use a more general formula: *the longer any particular colored light acts on the same retinal area, the less effective it becomes in producing a chromatic color-sensation: it will gradually produce the sensation of neutral grey.* We shall ascertain this law of local adaptation by the following experiment.

Experiment 66. (Local adaptation to colored light.) Mark the centre of a small colored square (say red) with an ink-dot and that of a larger square of exactly the same color (cut from the same paper) with a cross. Put the

two squares at some distance from each other on a sheet of white paper. Focus the ink-dot for more than fifteen seconds, say twenty-five. Now focus the cross in the centre of the large red square. Note the great difference in the effect which the same red light has on the red-adapted area of the retina and on the surrounding areas. The central portion of the large square looks almost neutrally grey, while the rest appears red.

After resting the eye ascertain in a similar manner the effect of local adaptation to other colors, yellow, green, blue, and so forth.

Experiment 67. (Local adaptation to darkness.) We proceed as in experiment 66, except that we now use two dull-black squares, one small, the other larger, each with a pinhole in its centre. We had several times occasion to point out that a piece of dull-black paper (or even velvet) is not absolutely black in the physical sense. The amount of white light, however, which it reflects is so slight that it remains ordinarily below the threshold of sensation. But after the central area of the retina has become dark-adapted, the same small amount of white light is—for this portion of the retina—distinctly above the threshold and causes the sensation of grey. It should be added, however, that simultaneous contrast enhances the effect of local dark-adaptation.

The effects of general adaptation to daylight and twilight are, in part at least, a matter of common experience. When we pass from broad daylight into a room but dimly illuminated, we are at first unable to see anything at all. But after some time we find to our agreeable surprise that there is really light enough for us to see the various objects in the room very clearly. Of course, these objects reflect exactly the same light now as they did when we first entered the room. But the same amount of light which was then below the threshold of sensation,—too slight to arouse a sensation,—is now distinctly above it. We were daylight-adapted before and now we are dark-adapted.

When we now pass into daylight again, our eyes are at first dazzled. The objects about us reflect no more light than they did before. But they reflect altogether too much for a dark-adapted eye and appear in consequence unusually bright. This "daylight-dazzle," however, does not last long. After a comparatively brief period of time objects assume again their ordinary appearance. We are again daylight-adapted.

The eye, then, has the marvelous power of adjusting itself to wide differences in general illumination: to the glare of the tropical sun and to the dim light of a coal-mine. This is due in part to the fact that the pupil of the eye automatically widens or contracts, according as the illumination is decreased or increased. But this is not all. For the widening and contracting of the pupil occurs promptly, as soon as the illumination is changed, while the ability to see objects under these altered conditions returns only gradually. The latter implies an adjustment of a different kind: a gradual change in the sensitiveness of the retina or, what comes to the same thing, a gradual change in the threshold-value of different intensities of light. This is the principal feature of the process of general adaptation to daylight and twilight. The changes in the apparent brightness of ordinary objects, seen under the same conditions of illumination, are its main effects, as far as they come under common observation.

There is, however, another and rather curious effect of twilight-adaptation which was first described by the Austrian physiologist Purkynje and is known as the Purkynje phenomenon.

7. The Purkynje Phenomenon. We said in the fourth chapter (p. 93) that yellow is the brightest color in the spectrum. This statement, however, needs a qualification. For it is not true when the eye is dark-adapted and the intensity of the spectral lights is greatly reduced. When these two conditions concur—dark-adaptation and reduction of light-intensity—then the relatively brightest portion

of the spectrum is green. At the same time red becomes considerably darker and blue distinctly brighter. The whole spectrum looks very different from what it does when the said two conditions are absent. This is the Purkynje phenomenon.

This change in the relative brightness of different colored lights occurs not only when they are of spectral purity, but also in the case of mixed lights, such as are reflected by colored objects in nature. In other words, in order to observe the Purkynje phenomenon it is not necessary to project a spectrum on a screen. At least the darkening of red and the peculiar whitening of blue which occur under the said two conditions (sometimes designated the Purkynje phenomenon in the narrower sense) can also be shown without any elaborate apparatus. The following simple experimental arrangement suffices.

Experiment 68. Materials: A piece of dull-black card-board of about the size of this page; a piece of red paper, about two inches square; a piece of indigo-blue paper of the same size.

Paste the two colored squares at some distance from each other on the dull-black card-board. Thus simultaneous color-contrast is fairly well eliminated and simultaneous brightness-contrast exists equally for both red and indigo-blue. On comparing their brightness in diffused sunlight we shall not hesitate to decide in favor of red.

Now reduce the illumination of the two colored papers. This may be done by placing the card-board in a dark corner of the room, or still better, in the following manner. Set up the card-board vertically on a suitable support at one end of the room and observe it from the other. Both colors will look darker but red will remain the relatively brighter of the two. Draw down the window-blinds so that only a little sun-light enters the room, just enough to see the card-board. By doing so we merely reduce the illumination of the two papers still further without becoming dark-adapted. For dark-adaptation is a slow process and

must have gone very far before we can observe the Purkynje phenomenon. Note that the blue square looks still darker, possibly so dark that we fail to distinguish it from the black background. But the other square remains plainly red and unquestionably brighter than its partner.

We may secure the other condition—dark-adaptation—by going into a completely darkened room and staying there for about twenty minutes. But this is not necessary. Simply wait for the experiment proper till an hour after sunset. By that time dark-adaptation has sufficiently advanced. The artificial illumination of the room will not interfere very much with this process, at least as far as the purposes of our present experiment are concerned. For a student's lamp is, after all, an insignificant source of light, when compared with the sun. An hour after dark, then, turn out the lamp, rest the eyes for a minute or two, and then look at the two colored papers near the window. They will be sufficiently illuminated by light from the street. In fact this illumination may be too strong. Hold the papers in such a way that you can just see them. Note that the red paper now looks black, possibly blacker than the card-board. But the other paper appears silvery-white with just a tinge of blue: unquestionably brighter than red.

Now turn on the lamp again and note that both colors look much the same as during daylight-adaptation: red is undoubtedly brighter than indigo-blue. From this we see that the Purkynje phenomenon does not occur unless both conditions—dark-adaptation and reduction of light—are simultaneously present (cf. Ebbinghaus, Gr. d. Psych., p. 204).

CHAPTER VI

COLOR-BLINDNESS, COLOR-WEAKNESS, AND INDIRECT COLOR-VISION

1. The Task before Us. We have so far ascertained the main facts and laws of normal color-vision. To complete our account of color-sensations we must also take into consideration three groups of phenomena which are distinct deviations from those set forth in the preceding chapters. They are the facts of color-blindness, color-weakness and indirect color-vision. All these anomalies are of exceptional interest in the discussion of the various theories of color-vision. Hence it is not surprising that the investigation of the former has been largely influenced by the latter. While it is hard to avoid all reference to these theories, we shall try to ascertain the facts independently of them. The theories themselves will be dealt with in the next chapter.

2. The Most Common Form of Color-Blindness: Red-Green-Blindness. In all probability the reader would be greatly surprised, if a friend of his were to inform him in real earnest that the color of grass is about the same as that of a brick-house; or that the flowers of a geranium differ from its leaves only in this that the former look considerably darker than the latter; or if, in choosing a necktie, he rejects one of a rich purplish-red color, because it looks pretty much like a slate on the roof, and picks out a bluish-green one, because it matches almost perfectly with his light-grey summer-suit. Surely there is something wrong somewhere. Well, the simple fact is, such a person is color-blind, or more specifically, he is red-green-blind. In using the latter term we imply for the present no particular theory of color-vision but merely signify the plain fact that *he can never be relied upon to distinguish between*

red and green. It is this form of color-blindness which has of late years attracted a good deal of attention because of the use of red and green signals on railroads and steamships.

Statistical records do not agree in stating the frequency of this anomaly. This is due to a number of causes but principally to the different methods employed in testing persons for color-blindness. It is safe, however, to say that at least two out of every hundred men we meet are red-green-blind. If also color-weak persons are included under the term "color-blind"—and for practical purposes this is to a certain extent justified, though it is theoretically incorrect—then the percentage is much greater. Curiously enough women are rarely affected by this anomaly, or rather, they have it as a rule only in a latent form. For it is through them that the anomaly is transmitted to posterity. This means in practical terms: a color-blind man has inherited this anomaly from his grandfather on his mother's side, and it will appear again not among his own children, but among the sons of his daughters. This is a matter of Mendelian laws of heredity and need not detain us here.

When a person makes such mistakes as those mentioned in the beginning of this section, it is plain enough that colored objects in nature and art look very different to him from what they do to normal persons, even though he designate their colors by the same terms as we do. But what in the world does he experience, when a brick-wall and grass look pretty much alike to him? Does grass look what we call red, or a brick-wall what we call green, or are both of a color which resembles neither red nor green? It would seem at first sight a hopeless task to find this out. But modern experimental methods have given us a clue to the situation so that we can say with fair accuracy what a red-green-blind person sees.

Color-blindness is as a rule congenital and affects both eyes. Sometimes, however, it is acquired so that the person affected can compare his present experiences with his

former ones. But more important than these are a few recorded cases of congenital color-blindness restricted to one eye, the other eye being normal. From the careful examination of such a case of red-green-blindness (reported by A. v. Hippel in Graefe's Archiv., vol. 26, 2, pp. 176 sqq., and vol. 27, 3, pp. 47 sqq.) we have the following information.

The abnormal eye agrees with the normal one in the sensations of all the neutral colors: white, black and grey; similarly in the sensations of yellow and blue. All the other colors are seen in terms of either yellow or blue or grey. If a spectrum is examined by the abnormal eye, there is a band of neutral grey in the bluish-green portion. All colors situated to the left of this neutral zone (that is, all colors of the red end) appear yellow, differing only in saturation and brightness; all those to the right of the neutral zone appear blue, differing likewise only in saturation and brightness (l. c., vol. 27, pp. 50-52).

If all red-green-blind persons have the same experience, it should be possible to produce on the color-wheel a valid match for any spectral or extra-spectral color by the combination of two or three of the following four disks: yellow, blue, white, and black. Now such is actually the case. With regard to extra-spectral colors in particular it is found that there is a certain purplish-red which appears as dark-grey. All the other purples are seen as shades of yellow or blue, according as they are more reddish or bluish than that which appears dark-grey. Consequently we have in the color-wheel a means of testing a red-green-blind person with accuracy and that without ever requiring him to designate any color by name. All that he is requested to state is whether two colors, presented to him, match or no.

When a sufficient number of subjects are thus examined, it is found that there are really two types of red-green-blindness. Though the general description, above given, fits both, they differ considerably as to details. Helmholtz called persons of the first type "green-blind," those of the second "red-blind." We shall not follow this terminology,

because it implies a theory and; moreover, one that does not fit the facts. Others have invented formidable Greek names, rather adding to the affliction which such persons have to bear. In order to avoid all theoretical implications we shall simply speak of the "first type" and the "second type" of red-green-blindness.

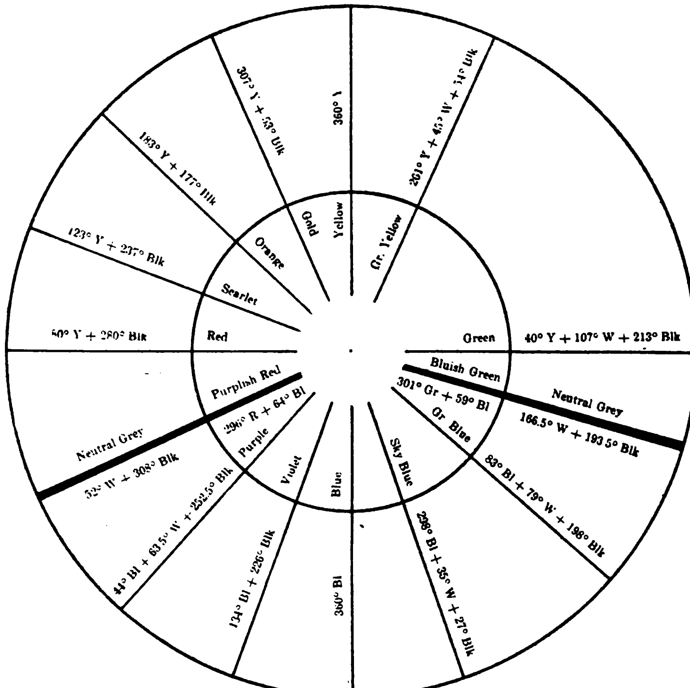


Fig. 28.—Diagram illustrating how *saturated* colors appear to red-green-blind persons of the FIRST TYPE. Note the two colors (*purplish red* and *bluish green*) which appear to them *neutral grey*. All colors above these two colors, are seen in terms of *yellow*; all those below them, in terms of *blue*.

3. Typical Color-Equations of Red-Green-Blind Persons of the First Type (the "Green-Blind" of Helmholtz). The color-equations, indicated in the accompanying diagram (Fig. 28) were actually made in the psycho-

logical laboratory of St. Louis University by a red-green-blind person of the first type. The same equations were acknowledged as approximately correct by a number of other persons of the same type. The differences which the latter found between the colors, matched by the former, were only differences of brightness and these, not great.

On the inside of the circle are the names of Hering's series of colored papers, known for their relatively high degree of saturation. On the outside are the combinations on the color-wheel with which the respective colors were matched. Only two colors on the inside of the circle, namely those which were matched with neutral grey, had to be produced by appropriate combinations of Hering's papers and are thus marked.

Experiment 69. Materials: Two color-wheels; set of disks like those marked in the accompanying diagram. The disks should be prepared from Hering's series of colored papers.

To test a person for red-green-blindness, proceed as follows:

(a) On the arbor of one color-wheel mount a plain red disk on a white background (a larger white disk); on the arbor of the second color-wheel mount on a similar background the combination marked on the right side of the following equation: 360° Red = 80° Yellow + 280° Black. The person to be tested should not see the two disks, before they are actually rotated, nor should he know which of the two is the plain, and which the compound disk. *He is requested to state whether the two disks match.* If they do so approximately, that is, if the compound disk differs from the other only slightly in brightness, a slight variation in the proportion of its sectors will secure a perfect match. This means that the person tested belongs to the first type of red-green-blindness. To make quite sure of this, follow the instructions given under (b) and (c).

If the person tested rejects the match entirely, proceed

as directed in Experiment 71, to find out whether he belongs to the second type of red-green-blindness.

(Note: The student may be surprised to find that the combination of a small sector of yellow with a very large one of black does not look dark-yellow, as might be expected, but *olive-green.* This does not denote any color-blindness, but is a peculiarity of normal color-vision.)

(b) As clinchers the following typical matches should be presented:

296° R + 64° Bl = 52° W + 308° Blk
301° Gr + 59° Bl = 166.5° W + 193.5° Blk
360° Gr = 40° Y + 107° W +213° Blk
360° Purple = 44° Bl + 63.5° W + 252.5° Blk

For his own information the student should rotate on the color-wheel also the other combinations, marked in the diagram. *He will thus get a fairly accurate idea of how saturated colors appear to persons of the first type of red-green-blindness.*

(c) Determine the threshold of color-sensation, as explained in the following experiment.

Experiment 70. Materials: Two color-wheels; disks as indicated below.

When discussing the threshold of color-sensation in the third chapter (n. 7, Exp. 24), we found that a slight addition of any colored light to white light, remains unnoticed; that is: Such a combination of lights will not arouse a chromatic color-sensation, but the sensation of some shade of grey. We saw further that different colored lights differ in this regard; that is: The eye is not equally sensitive to all colors. There are moreover individual differences, the threshold of any given colored light not being the same for all persons.

Red-green-blind persons are characterised by this that the threshold-values of red and green lights are abnormally high. In other words, there are many tints of red and green which are plainly recognized as such by normal persons but appear neutrally grey to red-green-blind persons.

The threshold-values of yellow and blue lights, however, are not far from normal; other colored lights have intermediate values. The two types of red-green-blindness differ also in this regard.

The following equations were actually made by the person from whom the matches of the preceding experiment were obtained.

232° Red + 128° W = 194° Blk + 166° W
102° Scarlet + 258° W = 72° Blk + 288° W
86° Orange + 274° W = 61.5° Blk + 298.5° W
60° Gold + 300° W = 3.5° Blk + 356.5° W
43.5° Yellow + 316.5° W = 29° Blk + 331° W
74° Gr. Yellow + 286° W = 86.5° Blk + 273.5° W
283° Green + 77° W = 116° Blk + 244° W
70° Gr. Blue + 290° W = 50.5° Blk + 309.5° W
26.5° Sky Blue + 333.5° W = 40° Blk + 320° W
16° Blue + 344° W = 14° Blk + 346° W
58.5° Violet + 301.5° W = 45° Blk + 315° W
189° Purple + 171° W = 161° Blk + 199° W

The student should rotate these disks on two color-wheels and note especially the remarkably plain tints of red and green which appear neutrally grey to a red-green-blind person of the first type.

4. Typical Color-Equations of Red-Green-Blind Persons of the Second Type (the "Red-Blind" of Helmholtz). The following diagram (Fig. 29) contains the color-equations which were actually made in the laboratory of St. Louis University by a red-green-blind person of the second type.

On comparing the present diagram with the former one (Fig. 28) the student will note that there occur two neutral zones in both, namely in the purplish-red and the bluish-green. All colors above these neutral zones are seen by persons of both types in terms of yellow; all colors below them in terms of blue. But the position of the two neutral zones differs. In the first diagram the purplish-red is more bluish and the bluish-green less bluish, than in the second,

and the "false yellows" of the first are more saturated, and the "false blues" less saturated than those of the second. Consequently, while persons of both types are undoubtedly blind to both red and green, those of the first are "relatively yellow-sighted," those of the second "relatively blue-sighted."

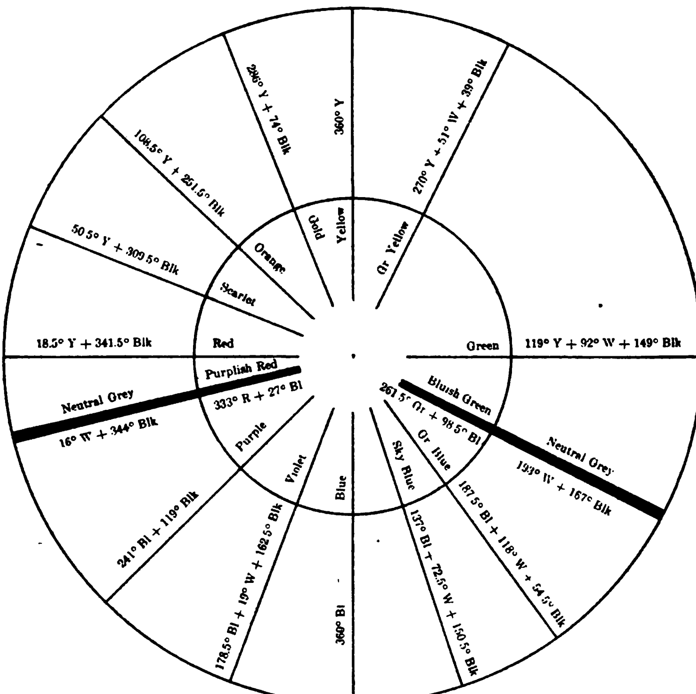


Fig. 29.—Diagram illustrating how *saturated* colors appear to red-green-blind persons of the SECOND TYPE. Compare the equations of this diagram with those of Fig. 28. Note the vast difference in the equations.

Experiment 71. Materials: Two color-wheels; disks, as indicated below.

To determine whether a person belongs to the second type of red-green-blindness, the following typical matches

should be proposed to him in the manner indicated in Experiment 69.

$$360° \text{ R} = 18.5° \text{ Y} + 341.5° \text{ Blk}$$
$$333° \text{ R} + 27° \text{ Bl} = 16° \text{ W} + 344° \text{ Blk}$$
$$261.5° \text{ Gr} + 98.5° \text{ Bl} = 193° \text{ W} + 167° \text{ Blk}$$
$$360° \text{ Purple} = 241° \text{ Bl} + 119° \text{ Blk}$$
$$360° \text{ Gr} = 119° \text{ Y} + 92° \text{ W} + 149° \text{ Blk}$$

Then the threshold-value for red, green, yellow and blue lights should be determined. The following equations indicate which tints of these colors appeared neutrally grey to the red-green-blind persons of the second type, above referred to.

$$319° \text{ Red} + 41° \text{ W} = \text{neutral grey}$$
$$272° \text{ Green} + 88° \text{ W} = \text{neutral grey}$$
$$93° \text{ Yellow} + 267° \text{ W} = \text{neutral grey}$$
$$5° \text{ Blue} + 355° \text{ W} = \text{neutral grey}$$

5. A Very Rare Form of Color-Blindness: Yellow-Blue-Blindness. There is another form of color-blindness of which only a few cases have been investigated. In some of them the anomaly was congenital, in the others, acquired. It was called by Helmholtz (in accordance with his theory) "violet-blindness." Hering terms it (in accordance with his theory) yellow-blue-blindness. Two types are described, *partly on theoretical grounds.*

For persons of the *first type* there are two neutral bands in the spectrum, namely in the yellow and the blue. All colors situated between these two zones are seen in terms of green, all colors outside of them (that is, those of both ends of the spectrum) in terms of red (cf. Pflüger's Archiv, vol. 57, [1894] pp. 311-313).

For persons of *the second type* there is only one neutral band in the spectrum, namely in the yellowish-green. All colors to the left of this neutral zone (that is, those of the red end) appear red or yellowish-red, those to its right, bluish-green or green (cf. Fröbes, Lehrbuch der Exp. Psychologie, I, p. 83, and J. v. Kries in Nagel's Handbuch, III., pp. 166-168).

It should be added that a condition similar to this anomaly can be artificially produced by a certain drug.

6. **Total color-blindness,** mostly congenital, sometimes acquired, has been ascertained in about 50 cases. To persons thus affected, the spectrum looks like "a delicately executed pencil-drawing." All colored objects in nature and art appear to them pretty much as a photograph of them does to normal persons (cf. Fröbes, l. c.).

7. **Color-weakness** is a rather vague term. It is sometimes used to designate nothing else than a lack of practice in discriminating and naming different colors. Such a lack of practice is, of course, consistent with perfectly normal color-vision. In this sense the vast majority of persons are color-weak.

In the narrower and more proper sense of the term color-weakness denotes a condition intermediary between normal color-vision and color-blindness proper. Persons, thus affected, distinguish readily between different colors, when the latter are of a high degree of saturation, or when colored objects are near-by and well illuminated. But unsaturated colors are liable to be confused with one another or with grey, especially when the objects viewed are beyond a certain distance or not well illuminated.

To a certain extent this is true in the case of every one of us. There are, moreover, individual differences in this regard which we have all along taken for granted when discussing the facts and laws of normal vision. Thus, for instance, we are not particularly astonished when, in determining the threshold of color-sensation, we find that one subject reports "neutral grey" and another "a slight tinge of green." Such individual differences, however, do not exceed certain narrow limits. The difficulty arises, when we try to give a definite meaning to these "certain narrow limits" so that we can say with precision: Here normal color-vision ceases and abnormal vision begins.

Color-weakness manifests itself also by the effects of contrast and adaptation. Of course we are all subject to these

effects. But most of them pass unnoticed by us, because the conditions which force them on our attention are as a rule absent. Thus, for instance, without steady fixation of objects no troublesome after-images will arise. There are, however, individual differences in this regard. When trying to verify these phenomena in Experiment 59, we called special attention to the fact that 15 seconds of steady fixation are not enough for some persons and a shorter period suffices for others. If the latter is the reader's case, then he approaches somewhat the condition of color-weak persons. For they are unusually susceptible to the effects of contrast as well as to those of adaptation. In popular language we should say that their eyes are very easily fatigued. Hence their slowness and uncertainty in describing the colors of unfamiliar objects. They will call one and the same object now grey, now slightly greenish, now again pinkish. As a matter of fact they are describing just what they experience on successive occasions, namely the effects of contrast which, in the case of normal persons, remain below the threshold. Here again it is difficult to say just where the dividing line is between normal and abnormal color-vision.

8. Indirect Color-Vision. Under certain conditions we are all color-blind, or rather color-weak, namely whenever we view objects with the periphery of the retina. Most persons never become aware of this curious fact. For whenever a colored object attracts our attention, we look at it directly; that is: We turn our eyes instinctively in such a way that its image falls on the central portion of the retina, the area of clearest vision. In the accompanying diagram (Fig. 30) rr′ denotes the retina of the eye, f the very centre of its area of clearest vision, Ff a ray of light causing a retinal image of F. Any object whose image falls on the area of clearest vision is said to be "focussed" or "seen directly." The color-sensation which it arouses is in accordance with the laws described in the preceding chapters.

With an effort, however, we are able to observe objects "out of the corner of the eye." Thus, for instance, while looking directly at F, we may observe T or any other object situated to the left or the right of F, above or below it in

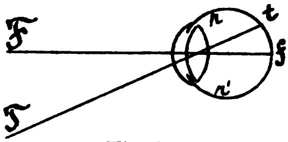


Fig. 30.

any direction whatever. The image of T falls under these conditions on a peripheral portion (t) of the retina. An object thus seen is said to be "seen indirectly." If we overcome our instinctive tendency to turn the eye in the direction of the object which attracts our attention, that is, if we keep focussing F, while observing T, then we find to our surprise that the color of T is changed. It looks very different from what it does when seen directly. What color-sensation it will arouse depends on the portion of the peripheral retina on which its image falls.

For the exact investigation of peripheral or indirect color-vision an instrument, known as the perimeter, is required. By means of it we can map out the whole retina and indicate the boundaries of three different zones. The middlemost or central zone yields normal color-sensations. The intermediate zone is in a condition very much akin to red-green-blindness, while the outermost zone is almost totally color-blind.

We shall not attempt so exact a determination of these three zones. For not only is this a rather difficult task to accomplish, but the zones as determined for one person do not coincide with those of another, nor are their boundaries under all conditions identical for one and the same person. The simple fact is that the two outer zones are color-weak rather than color-blind and—what makes the investigation doubly hard—subject in a most remarkable degree to effects of contrast and adaptation. Hence it makes a great difference whether saturated or unsaturated

colors are presented to the outer zones, whether the colored objects are large or small, whether they are viewed on this or that background. Accordingly not too much importance should be attached to the details of such exact zone-determinations nor to the series of changes which a definite colored object has been found to undergo when stimulating successively different portions of the peripheral retina.

The purpose of the following experiment is to ascertain the general fact that the periphery of the retina is in a condition akin to color-blindness so that, for instance, small red or green objects seen indirectly appear yellow or neutrally grey. This can be shown readily with an improvised form of perimeter such as will be described presently.

Experiment 72. Materials: A sheet of black, flexible card-board, about 25 inches square; pieces of red, green, yellow, and blue papers, each about one inch square.

With a pencil make an inch-scale in the middle of the black card-board, as indicated in the accompanying diagram (Fig. 31). At o fasten the small red square with a pin or in any other suitable manner. Then, holding the card-board with both hands at arms' length, bend it so that it forms part of a circle whose centre is the right eye.

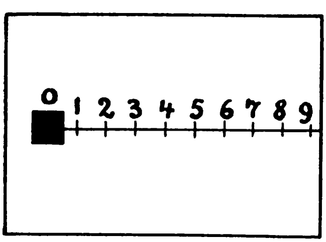


Fig. 31.

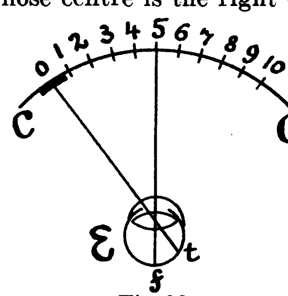


Fig. 32.

This arrangement, diagrammed in Fig. 32, is an improvised form of the perimeter, which enables us to explore the temporal half (t) of the retina of the right eye. The letters CC′ denote the card-board held as directed; o, the red square; E, the right eye (here represented as) focus-

sing 5 of the inch-scale. (To explore the temporal half of the retina of the left eye, C′ must be held in the left hand, and C in the right hand; if other peripheral portions of either retina are to be examined, the position of the cardboard must be varied accordingly, as needs no further explanation.)

The following precautions should be observed in experimenting. Spectacles, if worn by the observer, should be removed. While the right eye is being examined, the left should be closed or, preferably, blindfolded. The observer should turn his back to the window so that the right eye is not fatigued by the window-light and the red square is well illuminated.

Begin the experiment proper by looking directly at the red square, and note its color. Then we turn the eye quickly so as to focus 1 of the inch-scale and report to an assistant the first impression we get of the red square. After resting the eye, that is, closing it for a few seconds, focus 2 of the inch-scale and again report the first impression. In the same manner we focus successively the other numbers of the scale. We shall find that the outlines of the red square, thus seen peripherally, become more and more blurred, but its color changes. It will look gradually more orange-like, then yellowish, and at last neutrally grey. The assistant should record these changes and where they occur.

Observe in the same manner the changes of color which the green, yellow, and blue squares undergo, when seen indirctly.

On comparing the results of these four determinations we are able to indicate in a rough sort of way the boundaries of the three zones in the temporal half of the right retina.

It is stated—but very hard to verify by means of so simple an arrangement as that described—that a *certain purplish red and a certain bluish-green remain unchanged, before they become neutrally grey, and the change occurs in the intermediate zone;* and that a *certain yellow and*

blue remain unchanged in the central and intermediate zones and become neutrally grey in the outermost zone. *These four "stable colors" are considered the four physiological primaries ("Urfarben") of Hering's theory of color-vision* (cf. Seashore, pp. 23-38, and J. W. Baird, The Color-sensitivity of the Peripheral Retina, Publ. 29, Carnegie Institute).

CHAPTER VII

THEORIES OF COLOR-VISION

1. The Problem Stated. To one who has not only read the preceding chapters but actually performed the various experiments proposed it must be overwhelmingly evident that no color-sensation can be defined by merely correlating it with a definite kind of light, as defined in physics. There are a great many physically different kinds of light which are *physiologically equivalent* in producing the sensations of white and grey, as we ascertained experimentally in the third chapter. The experiments of the fourth chapter revealed a similar physiological equivalence of physically different kinds of light in arousing the sensation of any particular color-tone.

On the basis of these facts we reached the conclusion that every theory of color-sensation which purports to explain the properties of normal color-sensations by simply correlating them with definite properties of light must be ruled out. The problem which confronts us now is *to give a more definite meaning to this mysterious physiological equivalence of so many different kinds of light.*

A satisfactory theory of color-vision must further explain the striking effects of *contrast and adaptation.* How, for instance, does it come about that one and the same unchanging light arouses now the sensation of neutral grey, now that of red, blue, green, violet, purple, and so forth,— simply because the object reflecting the light in question is placed successively on different colored backgrounds?

From facts like these we drew the conclusion that *one portion of the retina exerts a profound physiological influence upon its neighboring portions.* The problem which confronts us now is *to give a more precise meaning to this physiological influence of the various portions of the retina upon one another,* so that we may understand at least the

regularities which all the phenomena of contrast exhibit. In particular we expect a more detailed account of the *physiological factor* which enters into the explanation of the most unique and the most familiar of all contrast-effects—*the sensation of black.*

Nor can the strictly abnormal phenomena of color-vision be ignored. For they are not "abnormal" in the sense that there is anything freakish about them. They are irregularities which exhibit definite regularities. Thus, for instance, the most ordinary cases of color-blindness conform to definite types which can be ascertained empirically. With regard to the rarer cases investigators have been less successful in tracing definite regularities. But the known types, as well as the puzzling varieties of color-blindness, should be rendered intelligible to us by *the absence* (or maybe the *modification*) *of one or more of the physiological factors of normal color-vision.*

In short, the tangle of facts which we have ascertained in the preceding chapters should be simplified for us by an account—experimental or hypothetical—of their physiological factors. Thus all the phenomena of normal and abnormal color-vision should be harmoniously co-ordinated and their why and wherefore made plausible to us.

It must be confessed that we have as yet no theory of color-vision which satisfies all these requirements. It is the purpose of the present chapter to discuss the relative merits of the two principal theories which have been advanced. Before doing so we shall premise a few remarks about the structure and the function of the eye.

2. Some Elementary Facts concerning the Structure and the Function of the Eye. The eye is constructed after the manner of a photographic camera. The principal portion of it which concerns us now is the sensitive film at the back of this camera, known as the retina. Though less than half a millimeter thick, it consists of several layers and contains millions of minute structures, called rods (a in Fig. 33) and cones (b). They are connected in a rather

complex manner with the ganglion-cells (G, g, h, i, j, k) and fibres (H) of the optic nerve.

It is these rods and cones, and not the fibres of the optic nerve, which are the real end-organs of vision and must be acted upon by light. A rough illustration will help us to understand their function. If we want to speak to some one over the telephone, it will not do to speak directly into or at a telephone wire. We must speak into the attachment of the wire, that is, the telephone proper. Every rod and cone is such a telephone proper. The fibres of the optic nerve simply conduct the physiological disturbance, produced in the rods and cones, first to a relay station in the lower portion of the brain, then at last to the centre of vision in the occipital lobe of the brain (not indicated in the diagram). When our telephone will not work or does

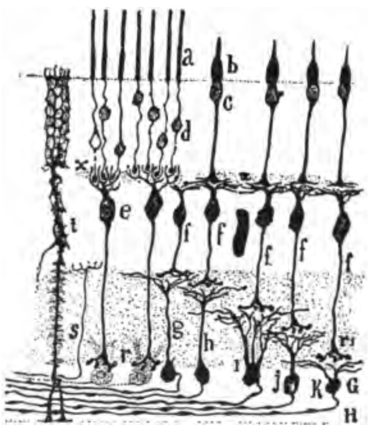


Fig. 33.—Schema of the structure of the human retina (after Ramon y Cajal, from Ebbinghaus).

so only imperfectly, there may be something wrong in the central station or in the conducting wires or in the terminal attachments, Just so it is in the case of color-vision.

Direct microscopic examination of the rods and cones, or the fibres, or the cerebral centres, reveals nothing which could help us in describing the physiological factors of

normal or abnormal color-vision. *We must do so in hypothetical terms.*

3. The Young-Helmholtz Theory. This theory was first proposed by Thomas Young (1807) and elaborated by H. von Helmholtz (Phys. Opt., 2 ed. 1896, pp. 346 sqq.). It starts out from the fact that the sensation of every color-tone, and that of neutral white or grey as well, can be aroused by the combination in different proportions of "three physical primaries", preferably by red, green, and blue-violet lights (cf. pp. 87 sqq.). Young therefore postulated three sets of nerve-fibres in the eye. The first, if stimulated alone, would mediate the sensation of red, the second and third, the sensations of green and blue-violet respectively. But none of these fibres is normally stimulated alone; every one of them is affected by every kind of light. The extent of this stimulation depends on the wavelength and differs from one set to another. The fibres of the first set are peculiarly sensitive to the long waves, those of the second to the waves of medium length, those of the third to the short waves. In the accompanying diagram (Fig. 34) the different kinds of monochromatic light are indicated by the letters R, O, Y, G, B, V. The three curves indicate to what extent the three sets of fibres (1, 2, 3, in the order above mentioned) are stimulated by them.

Helmholtz modified this theory by substituting for the three sets of fibres three kinds of photochemical substances in the end-organs of vision and three sets of ganglion-cells in the cortex of the brain. The three photochemical substances are decomposed in different degrees by the various kinds of light. The nerve-fibres merely conduct the excitation, thus set up in the end-organs, to the cortical centres (l. c. pp. 349, sq.).

According to this theory, then, *normal color-vision is trichromatic.* That is to say, every color-sensation—except that of black—is due proximately to a physiological process which is in every instance a combination in different proportions *of three elementary processes,* namely those set up in the red-, green-, and blue-violet-substances.

This hypothesis makes it easy to understand why so many physically different lights are physiologically equivalent in arousing one and the same sensation. For every kind of light acts on all three photochemical substances, only in a different degree. Hence all those kinds of light which stimulate the three substances in the same definite proportions, are physiologically equivalent. Thus, for instance, the sensation of yellow is aroused not only by a definite monochromatic light but by any combination of lights which act on the three substances in the proportions indicated in the diagram by a vertical erected over Y. The same is true of all the other colors. The sensation of white arises whenever all three substances are acted upon equally and in maximal intensity; the sensation of grey, whenever all three substances are acted upon equally but in a lesser degree of intensity.

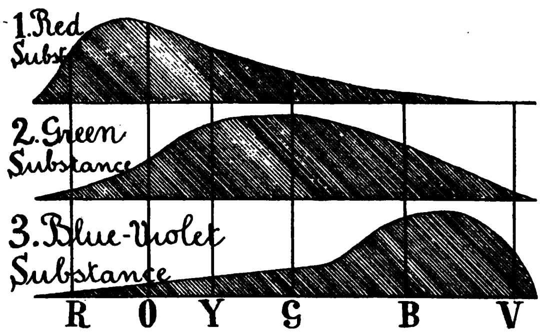


Fig. 34.—Diagram illustrating the Young-Helmholtz Theory (after Helmholtz).

In the explanation of the other facts of color-vision the theory of Helmholtz is less successful. Thus it is hard to see how his physiological factors can account for the *phenomena of simultaneous contrast*. Nor did Helmholtz attempt any physiological explanation of them. He ascribed them to an error of judgment. A strip of grey paper, for instance, when placed on a red background and covered with a piece of white tissue-paper, appears tinged with bluish-green. We are led to think so, because we

imagine the red background to be transparent, so that we seem to see the color of the strip through that of the background. In other words, the red background acts like the polished surface of a mahogany table in which we see the reflection of some other colored object: we see the color of the latter through that of the former. Now we know that the strip of paper, thus seen, must have the color which is complementary to red, that is, it must be bluish-green if it is to appear grey. Hence we judge the grey paper to have a tinge of bluish-green (cf. Phys. Opt., pp. 563 sqq.). The answer is that the phenomena of simultaneous contrast are observed also by those who know nothing about complementary colors and are therefore incapable of such "misleading considerations".

The sensation of black occurs, according to Helmholtz, whenever the retinal elements are not stimulated at all; that is, whenever they are in a state of physiological rest. This means that a positive sensation arises in the absence of both external and internal stimuli: a thing which is unintelligible.

The phenomena of successive contrast were attributed by Helmholtz to fatigue of the retinal elements. Thus by the steady fixation of a small red square the red-substance is acted on more than the other two substances and becomes thereby fatigued. When we look then at a white or grey surface, the latter does not stimulate the three substances equally, but mainly the green- and blue-violet-substances. Hence the complementary after-sensation of bluish-green. This seems plausible enough. But the theory fails to explain why the phenomena of successive contrast do not interfere with normal color-vision. For fatigue sets in very readily and in the course of a day all three substances are acted upon uninterruptedly. Hence we should be continuously troubled with after-sensations and at last become incapable of seeing at all. This, however, is not the case. In other words the fatigue-theory should be supplemented in such a way that we understand why the cerebro-retinal elements recuperate so readily.

Partial color-blindness was explained by Helmholtz by the absence of one of the three photochemical substances in the eye. Hence he distinguished three kinds of partial color-blindness, red-blindness, green-blindness, and blue-violet-blindness. Simply cover with a small strip of paper the first curve of the above diagram (Fig. 34), then the second and the third in turn, and we have a diagrammatic representation of the physiological factors which are responsible for the color-sensations, as they are experienced by the three classes of partially color-blind persons. If we want to find out, for instance, how a yellow disk appears to a red-blind person, we simply note the proportions in which the green- and blue-violet-substances are affected by it. They are indicated by the vertical erected over Y. We then make a compound disk with green and blue-violet sectors in the same proportions; add, if necessary, a sector of black or white or both, to regulate the saturation and brightness of the resulting color. By rotating the combination on the color-wheel we should produce not only a valid match for the plain yellow disk, as seen by a red-blind person, but we should find out for ourselves how he sees it. Proceed likewise in the case of a green-blind person, except that we use red and blue-violet sectors instead of green and blue-violet ones. Thus we should find out that *yellow looks like a shade of bluish-green to a red-blind person and like a shade of reddish-purple to a green-blind person.*

Unfortunately for the theory this does not tally with the facts which we ascertained in the preceding chapter. They all point to the conclusion that the "red-blind" as well as the "green-blind" of Helmholtz are blind for both red and green in the empirical sense explained in the last chapter. With regard to yellow in particular we know for certain that at least one red-green-blind person—the one who was color-blind only in one eye, while the other was normal—had exactly the same experience as normal persons. We have no reason to doubt that the same is true of all the ordinary cases of red-green-blindness. For this

Helmholtz has no explanation to offer. We know similarly that all red-green-blind persons agree with normal ones in the sensations of white and grey. This again is unintelligible in the theory of Helmholtz, as all three photochemical substances are required for these sensations. For the same reason the phenomena of peripheral color-vision remain unaccounted for.

These difficulties, to which some others might be added, make it impossible to accept the theories of Young and Helmholtz in their original forms. Hence the followers of Helmholtz have modified the latter's theory in various ways so as to eliminate its objectionable features. It would lead us too far afield to discuss these modifications in detail. (A brief account of them may be found in Fröbes, Exp. Psych. I, p. 85.) Accordingly *we must leave the question open whether the Helmholtz theory, thus modified, is acceptable or not.*

4. **Hering's Theory.** Hering, like Young and Helmholtz, postulates three visual substances which are sensitive to light. They may be characterized briefly as the *red-green-substance,* the *yellow-blue-substance,* and the *white-black-substance* respectively, as will be explained presently. Like all living matter these substances undergo continual changes which are known collectively by the name of *metabolism* and consist of *two antagonistic part-processes.* The living matter is broken down: this destructive process is called *dissimilation* (or katabolism). If left to itself the living substance will by a process of self-regulation build itself up again: this constructive process is called *assimilation* (or anabolism). When the visual substances are acted upon by light, either of these antagonistic processes may be *in excess* of the other or they may be *in equilibrium.* It is the combination in different proportions of these antagonistic processes in the three substances which are proximately responsible for the whole variety of normal color-sensations.

Excess of dissimilation in the red-green-substance is—

of itself—associated with the sensation of red ("Ur-rot", "original red" in Hering's terminology); excess of assimilation with the sensation of green ("Ur-grün"); equilibrium of the two processes with no sensation at all.

Excess of dissimilation in the yellow-blue-substance is—of itself—associated with the sensation of yellow ("Urgelb"); excess of assimilation with the sensation of blue ("Ur-blau"); equilibrium of the two processes with no sensation at all.

Dissimilation at its maximum in the white-black-substance is—of itself—associated with the sensation of brilliant white; assimilation at its maximum with the sensation of pure black; the combination of the two processes in various proportions—equilibrium included—with the sensations of the various shades of grey.

We said "of itself". For normally all three substances are acted upon simultaneously and by every kind of light. But the effect of the latter differs with its wave-length and from one substance to another. The details are illustrated by the accompanying diagram (Fig. 35) in which the straight line rg denotes the red-green substance, yb the yellow-blue-substance, WB the white-black-substance. The curves above each line denote processes of dissimilation, those below, processes of assimilation. The various kinds of monochromatic light are indicated by the letters R, O, Y, G, B, V. The vertical lines above each letter indicate to what extent and in which sense the different kinds of monochromatic light act on the three substances.

In the red-green-substance the long waves up to Y cause dissimilation, Y to B assimilation, and B to V again dissimilation in the proportions indicated by the respective curves. In the yellow-blue-substance R to G produce dissimilation and G to V assimilation. In the white-black-substance all rays produce only dissimilation, whose maximum lies above Y. The process of assimilation in this substance is not marked at all in the diagram. For it does not occur as a direct response to light but *only* by a process of self-regulation of the substance.

These are the salient features of Hering's theory. It explains just as readily as that of Helmholtz why so many different kinds of light are *physiologically equivalent* in arousing one and the same sensation. To begin with the sensations of *white and grey.* Every light, no matter what its physical constitution may be, produces dissimilation in

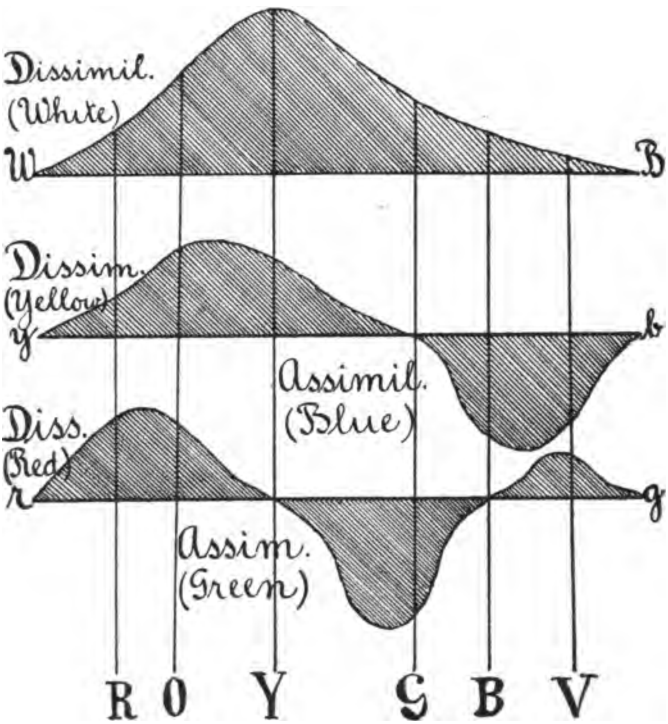


Fig. 35.—Diagram illustrating Hering's Theory (after Ebbinghaus, modified).

the white-black-substance. This process will actually arouse the sensation of white or grey, *provided the antagonistic processes in the other two substances are in equilibrium.* The latter occurs when the eye is acted upon by

all the wave-lengths of unfiltered sunlight, as a glance at the diagram shows. It occurs also in the case of any pair of complementary lights as well as of any combination of such pairs of lights, and may occur just as readily by the combination of three or any number of lights, provided the latter be appropriately chosen. *Consequently the sensation of white is in every instance due to one and the same physiological factor, namely, the excess of dissimilation in the white-black substance.* The relative amount of the simultaneous process of assimilation determines whether we have the sensation of this or that shade of grey.

A chromatic color-sensation, say that of orange, arises whenever the three visual substances are acted upon to the same extent and in the same sense as is indicated by the vertical line over O. This occurs not only in the case of monochromatic orange light but also in that of any appropriately chosen mixture of lights. When the components of this mixture act in opposite directions on the same substance—some producing dissimilation, the others assimilation,—only that process determines the nature of the resulting sensation which is in excess of the other. Consequently there is no difficulty in conceiving that many different combinations of light may affect the three substances to the extent and in the sense which is indicated by the vertical over O. The same applies to every other chromatic color-sensation. *Hence the sensation of one and the same color-tone is in every instance due to one and the same physiological disturbance.*

The phenomena of simultaneous contrast are explained by the following supplementary hypothesis. When light impinges upon one portion of the retina, it has not only a *direct* effect upon the latter but also an *indirect* one upon the other portions. This is in accord with the general biological fact that all the parts of a living organism, and particularly those of one and the same organ are interdependent in their functions. It is really the whole organism as a unit which responds in every instance to

external stimuli. The indirect effect of light, thus produced, is assumed to be *antagonistic to the direct effect* and to be strongest in the immediate neighborhood of the portion directly stimulated. The disturbance of equilibrium, created by the intruder in one portion, is, as it were, counteracted and offset by the spontaneous action of the adjacent portions. If, for instance, the red-green-substance in one portion of the retina is broken down, the neighboring portions begin spontaneously a building-up process of the same substance. *From this simple hypothesis all the regularities of simultaneous contrast which we ascertained empirically can be theoretically deduced, as needs no further explanation.* The sensation of black, in particular, is thus most satisfactorily accounted for. It is a positive sensation and correlated with a positive physiological process: that of assimilation in the white-black-substance. In one word, *the sensation of black is an indirect effect of light.*

The phenomena of successive contrast can be deduced from the antagonism of the two physiological processes in each visual substance. When, for instance, we fixate steadily a small red square, the red-green-substance is particularly broken down. When we look next at a grey surface, the building-up process in the same substance is in the ascendency. Hence the complementary after-sensation. As this and similar phenomena are really due to a continual process of self-regulation in the living substance, *we understand also why the retina recuperates so readily after fatigue.*

The facts of indirect color-vision are due to the unequal distribution of the three visual substances over the retina. In the central zone all three are present; in the intermediate zone the red-green-substance is lacking or nearly so, while the outermost zone possesses only, or almost only, the white-black-substance. It is to be noted that the four "stable colors" of indirect vision (p. 135) are assumed by Prof. Hering to be the four "original colors" ("Ur-

farben''), mentioned above. Three of them are indicated in the diagram by the letters Y, G, and B. The verticals above the latter make it clear why they are ''Urfarben''. ''Original red'' (a slightly-purplish red) is an extra-spectral color.

Color-blindness is explained by the absence of one or two of the visual substances in the entire retina. *Thus red-green-blindness is due to the absence of the red-green-substance.* This explains why persons in this condition experience white and black and all the shades of grey, and of chromatic colors only yellow and blue in all their tints and shades. A glance at the diagram makes this clear. *We fail, however, to understand—and this is a weak point in the theory—why there are two sharply divided types of red-green-blindness.*

The rare form of partial color-blindness is accounted for by the absence of the yellow-blue-substance and is, accordingly, called yellow-blue-blindness. There is, however, no case on record in which the phenomena observed tally precisely with those which this hypothesis leads us to expect. Hering explains this by saying that persons of this class are at the same time somewhat red-green-blind. *Be this as it may, the second type of yellow-blue-blindness cannot thus be accounted for. This is another weak point in Hering's theory.*

Total color-blindness is due to the absence of both the red-green-substance and the yellow-blue-substance. Accordingly only the white-black-substance remains and is responsible for all the sensations which are experienced by persons in such a condition. This is readily understood.

If we compare now the rival theories of Helmholtz and Hering, the balance of evidence seems to be decidedly in favor of the latter. The difficulties, however, which we have mentioned—and others might be added—require some modification of the original theory or must be met by some supplementary hypotheses. The most notable effort in this direction is that of Prof. G. E. Müller. It would exceed

the limits of an elementary text-book to discuss the details of this further elaboration of Hering's theory. We refer the reader to the text of Fr. J. Fröbes, S. J. (Lehrbuch der Experim. Psychologie, I, pp. 61-65, and pp. 86-89). The principal drawback in this Hering-Müller-theory would seem to be that the physiological factors of color-vision are rather complicated.

CHAPTER VIII

THE VISUAL PERCEPTION OF SPACE

1. The Problem before Us. From the outset it must be borne in mind that in this and the following four chapters we are not concerned with the reality of space, but with the manner in which we cognize it. This problem is a rather intricate one, and that for various reasons.

First of all, various senses contribute to our perception of space and their data are inextricably interwoven in our adult experience. We must artificially separate these various data, especially those furnished by the senses of touch and sight, for theirs is undoubtedly the lion's share. In these chapters we are exclusively concerned with our visual perception of space.

In the second place we perceive space both monocularly and binocularly, but the manner of cognizing it is very different in the two cases. Hence monocular and binocular perception of space must be treated separately.

In the third place, the very nature of the problem demands that we distinguish the perception of the direction of objects from that of their distance or the perception of the third dimension.

We shall proceed in our discussion as follows. In the first place we shall consider the monocular perception of the direction of objects; then the monocular perception of their distance; then the binocular perception of their distance; and lastly the binocular perception of their direction.

I. THE MONOCULAR PERCEPTION OF DIRECTION.

2. The direction in which we see objects with one eye depends on the points of the retina stimulated: every impression made on the retina is referred back into space

along the line of the unbroken ray which causes the impression.

The accompanying diagram (Fig. 36) will assist the student to understand the meaning of the law stated. Light coming from different points (a, b, c) of an object reaches different points (a′, b′, c′) of the retina. The straight lines connecting these corresponding points of the object and retina pass through the optical centre or nodal point (o) of the eye. They represent the *unbroken* rays of the light which stimulates the retina, and it is along these lines that we refer the impressions back into space: *they are the lines of visual direction.*

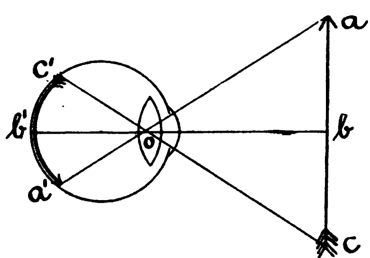


Fig. 36.

If it be asked, therefore, why we see objects in one direction rather than another, the answer is: In normal monocular vision the reason for this lies both in the objects seen and in the impression they make upon the eye. Various objects occupy different positions in space, they really lie in definite directions with reference to one eye; and the impression they make upon the retina corresponds point for point to these actual directions. It is this correspondence between the points of the retina stimulated and the actual directions which objects have with reference to one eye, which is the basis for the monocular perception of the direction of objects.

As will be seen from the above diagram, every object reflecting light into the eye causes an inverted image of itself on the retina, and every point of this image corresponds to a definite point of the object. Hence we may

also say that the inverted image of an object is the basis for seeing its parts in different directions. This statement, however, must not be construed to mean that we cognize first this inverted image and from it construct, as it were, the topography of our retina, and on the basis of the knowledge thus gained project the impression made on point a′, in the direction of point a in space, and the impression made on point b′, in the direltion of point b, and so forth. From mere internal experience we are not even aware of the fact that objects cause inverted images of themselves on the retina. In fact we do not even know that there is such a thing as a retina in our eye, just as —by internal experience—we are not aware that we have a brain and that our eyes are connected with the brain by means of nerve-fibres. All such knowledge we gain from books or more directly in the anatomical dissecting room. Examining an excised eye of man or a vertebrate animal we find that it is constructed in every detail after the manner of a photographic camera, and that the retina in particular is for the eye what the sensitive plate is for the photographic camera. Knowing the physics of light we can construct the formation of the image of an object on the retina. We thus find that the image must be inverted, and under appropriate conditions we can actually observe such an inverted image on the retina of an excised eye. All such knowledge, however, is not only far removed from our internal experience, but even after we have gained this knowledge in the manner stated, it helps us nothing in the cognition of the direction of objects seen in space.

In a word, then, the inverted retinal image and the topography of the retina are *no criteria* for us by which we are guided when perceiving the direction of objects in space. *We need no such criteria.* We externalize an impression made upon a definite retinal point in the direction of a definite point in space, because this is the *innate* and *constitutional* property of this point of the retina. And when we call this property *"innate,"* we do not imply thereby what goes in philosophy by the name of *"innate*

ideas'' or ''*Kantian forms*'' or anything of the sort. What is meant by the whole phrase is simply this: *the direction of objects seen monocularly is an immediate datum of our visual experience.* It is in this sense that we accept what is known as the ''nativistic contention''.

3. The Local-Sign-Theory. A number of psychologists deny the nativistic contention and maintain that our monocular perception of direction is in no sense immediate but gradually acquired by processes of association. In other words, the visual perception of direction does not depend *directly* on the retinal points stimulated but *indirectly* only. This theory is known as ''empiricism'' or more specifically as the ''local-sign-theory''.

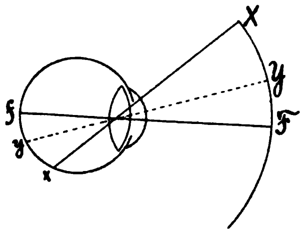


Fig. 37.

Suppose we are looking directly at object F (in Fig. 37). While we do so, a number of other objects (or other parts of the same object) form their respective images on peripheral portions of the retina. Such is, for instance, object X. If the latter attracts our attention we instinctively move the eye in such a way that its image falls on the central portion (f) of the retina. It is only thus that we can get a clear view of it. In other words, *in order to see X clearly, we must rotate the eye through the arc FX (or fx).* If object Y had attracted our attention, we should have had to move the eye through the arc FY (or fy).

Though these fixation-movements occur as a rule altogether involuntarily and automatically, we become aware of them, when they occur, just as, with closed eyes, we

become aware of the movements of our arms, no matter whether they are voluntary or involuntary. Such sensations of movements of our own body are known as "kinaesthetic sensations".

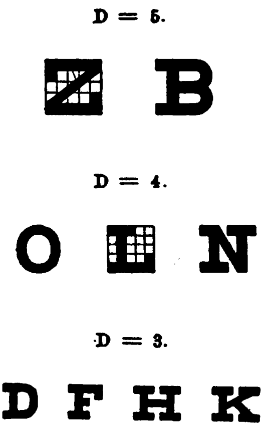
It is these "kinaesthetic sensations", arising from the movements of the eye, on which—it is claimed—our monocular perception of direction depends. They become *clues, criteria* or *"local signs"* by which we judge the direction of objects seen. For just as we can judge the position of, say, the right arm from the extent of the movement necessary to reach this position, so from the extent of the eye-movement, necessary to fixate a definite object, we are able to judge its direction. Plainly it requires less of an effort to rotate the eye through arc FY than through arc FX. Hence the difference in our judgment. It is thus that our perception of direction is originally acquired.

Once this association is firmly established, that is in adult life, we judge the direction of objects seen even in the absence of the actual eye-movements. *The mere stimulation of the retinal point x arouses the memory image of the corresponding fixation-movement.* That is to say, we imagine this movement and remember the effort needed to execute it, and *in virtue of this association we localise x in the direction of X.* "To see anything 'to the right' or 'to the left' of the line of vision (fF in our diagram) means nothing more than this, to be conscious of the magnitude of the achievement which would be necessary to bring the object into this line" (Outl. of Psych. by Lotze, transl. by Ladd, p. 57).

4. Experimental Tests of the Local-Sign-Theory. The following experiments are devised to test this hypothesis.

Experiment 73. Place the accompanying figure, known as Snellen's test-letters (from Nagel's Handbuch, III, p. 349) on a suitable support in such a way that it is well illuminated by diffused sunlight. Then let somebody who does not know which letters are contained in the figure be stationed at a distance of 5 meters (about 16 feet) away

from the book. If his eye-sight is normal, he should be able to recognize the two upper letters. Those of the second and third rows should be legible at a distance of about 4 and 3 meters respectively. It is in this manner that persons are tested by an oculist before he prescribes a pair of spectacles. The eyesight of many, even when they use



Snellensche Probebuchstaben für 3, 4 und 5 m Distanz.

Fig. 38.—Snellen's Test-Letters (from Nagel's Handbuch).

properly adjusted glasses, falls below this standard, but that of others is considerably above this standard even without the aid of glasses. We shall return to this presently.

Now note carefully what normal eyesight means in more exact terms. The letter B (of Fig. 38) seen from a distance of 16 feet, subtends a visual angle of 5 minutes and its every single line, a visual angle of one minute. To understand this, look again at the diagram (Fig. 37) with which we illustrated the local-sign-theory. Magnify this diagram, that is, imagine one of your eyes to be the centre of a circle whose radius is 16 feet. This circle is divided into 360 degrees (°), each degree into 60 further parts, known as minutes (′), each minute into 60 further parts, known as seconds (″). When the letter B (of Fig. 38) is placed at

the circumference of this circle, it occupies an arc of 5 minutes and its single lines occupy each an arc of 1 minute.

We said that the eyesight of some persons is keener. The most remarkable records are those of some illiterate persons. (The latter are tested by means of printed hooks, resembling the letter E and pointing in different directions.) Thus an Egyptian boy recognized the direction of the hooks correctly at a distance of 48 meters (about 156 feet). The single test-objects, thus seen, occupied less than an arc of 8 seconds (7.5″) or about one-eighth of a minute-arc (cf. Nagel's Handbuch, III, p. 350).

Let us see now whether the local-sign-theory can account for these facts of visual acuity. If we recognize the standard test-letters under the normal conditions mentioned, we localise their component parts each in its proper direction. If in doing so we are guided by the sensations arising from the fixation-movements, we must rotate the eye through an arc of one minute, in order to fixate each recognizable part. We must, moreover, become conscious of each fixation-movement and of the effort needed to execute it. In the absence of these actual movements we must imagine them and remember the effort needed to execute them. And the Egyptian boy, whose visual acuity was eight times above the normal, had to execute fixation-movements which are eight times more delicate, or else remember the effort needed to execute them.

The plain fact is that no one can execute such delicate fixation-movements. Each test-letter of standard size—in fact one of twice or three times the standard size—is what goes in the psychological laboratory by the name of a fixation-"point", if the observer is stationed at the prescribed distance. At reading distance an ink-dot, a small cross or any one of the letters, printed on this page, is a fixation-"point" and when we observe a church on the distant horizon, the whole church is a fixation-"point". And this leads us to a more fundamental consideration.

All this talk about "points" in space and retinal "points" stimulated, as understood in the local-sign-theory,

is based on a metaphysical abstraction which is far removed from the facts as they occur. A mathematical point in space cannot be seen nor is the retina ever stimulated in a mathematical point. "Points" in space and retinal "points" are "areas", small areas, it is true, but true areas. In other words, when we fixate a "point" in space as steadily as we can, this "point" has recognizable parts which are situated in different directions and are actually localised in different directions. The conditions for this localisation are given in the retinal "point", that is, the small retinal area stimulated. This localisation occurs independently of any fixation-movements or the sensations arising from them. *In the light of these plain facts the local-sign-theory is untenable.*

Experiment 74. Close one eye and look at any particular "point" in the circumference of the larger circle in Fig. 39, without previously marking that point with a pencil or otherwise. Then follow the contours of the circle, that is, move the eye around the circle. Pay particular attention to the kinaesthetic sensations arising from these successive fixation-movements. Can you—*on the basis of the kinaesthetic sensations, introspectively ascertained,*—judge

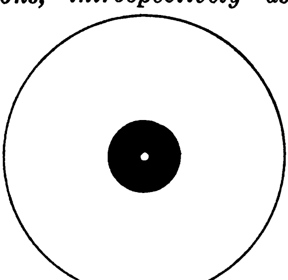


Fig. 39.

that you have moved the eye in a circle? In the local-sign-theory this ought to be possible. Write down your introspective report before you continue the experiment.

Now fixate monocularly the white dot in the centre of the small black disk in the same figure. Continue to do so

for about 30 seconds, timing yourself by counting slowly 30. Then project the white after-image of the black disk on some point of the large circle and move the eye again around the latter. By observing carefully the successive positions of the after-image you can tell how accurately you execute such successive fixation-movements. Note how jerky and crooked they are.

By means of a very elaborate arrangement, which need not detain us here, a similar movement of the eye "around" a circle has been actually photographed. Fig. 40 is a reproduction of the result (cf. Philos. Studien, Vol. 20, p. 342).

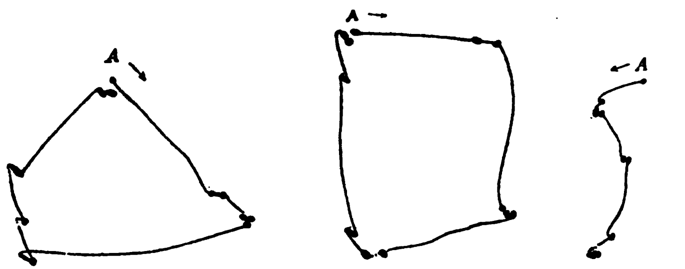


Fig. 6.

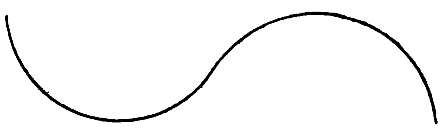


Fig. 40.—Eye-movements photographed by G. M. Stratton. The upper left-hand figure shows how the eye moves "around" a circle; the next figure, how it follows the contours of a rectangle; the right-hand figure, how it follows the curve indicated below and marked Fig. 6. (From Phil. Studies, l. c.)

If the monocular perception of the direction of objects depended really on such fixation-movements and the sensations arising from them, we would construct for ourselves a rather crooked universe. Plainly the local-sign-theory is out of joint with facts.

Experiment 75. Look with one eye at the brightly illuminated clouds and note the bright specks in your field of vision, sometimes clustered together in various ways, and dancing about like gnats. They are known as "muscae volitantes" and are due to shadows cast by minute bodies which are floating in the neighborhood of the retina (cf. Helmholtz, Phys. Opt., p. 201).

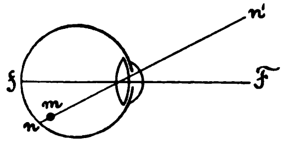


Fig. 41.

Let Ff (in Fig. 41) represent your line of direct vision, m, a floating body near the retina, n, a peripheral point of the retina, stimulated in the unusual manner indicated. (The details of the stimulation in this and similar "entoptic phenomena" are somewhat complicated.) As a result of this stimulation you see a bright speck in the direction of nn′. From this you see that the law stated in the last paragraph holds also in abnormal conditions: *every impression on the retina, no matter how it is made, is referred back into space along the line of the unbroken ray which would normally cause such an impression.* And, what is more important, *this localisation of the impression is altogether independent of any fixation-movement or any sensation arising from the latter.* Just try to fixate any one of these bright specks. As soon as you move the eye, the speck will run away from you. The fact is, you cannot possibly focus the speck. For to do so would mean that you bring the speck into line with f. But this is impossible.

There are many other phenomena which are due to peculiarities of the eye itself and are therefore known as "entoptic phenomena". Perhaps the most interesting of them is that known as "Purkynje's blood-vessel-figure". By any one of the three methods, originally described by the Austrian physiologist Purkynje, we may observe a highly magnified image of the blood-vessels in the retina

of our own eye. The third method, indicated in Helmholtz's Phys. Opt., p. 197, is the simplest.

None of these entoptic phenomena can be explained in the local-sign-theory.

Experiment 76. (Le Cat's experiment). Make a pinhole in a piece of card-board and hold the latter against the brightly illuminated clouds about 3 inches away from the eye. Bring the head of a pin close to the eye. The pin itself cannot be focussed accurately but it causes a large circle of diffusion. The same is true of the pin-hole in the card. Hence you get a very indistinct vision of the pinhead itself and the pinhole is seen enlarged. The pinhead, however, is in a very favorable position to cast a sharp and steady shadow on the retina, and this shadow is not inverted. By contrast the latter causes internal changes in the retinal area thus shielded from light. The result is the sensation of black, *which is externalized according to the law of monocular visual directions.* Behind the pinhole in the card you will see the black pinhead and a part of the pin itself. Its position is always the opposite of that which the real pinhead has in front of the eye. If you hold the pinhead upwards, the projected black pinhead will point downwards; if the former points to the left, the latter will point to the right, and so forth. *The localisation of the black pinhead is independent of any fixation-movement for the same reason as that indicated in the last experiment* (cf. Helmholtz, l. c., p. 201, and Sanford, p. 185).

Experiment 77. Materials: A reading glass or any convex lens, preferably of short focus.

Look at this page through a reading-glass, holding the latter in front of one eye. When you can see the print clearly, move the lens up and down. Note that the print moves apparently in the opposite direction. The following three diagrams (Fig. 42, 43 and 44) will help us to understand the reason for this phenomenon and that it is in accordance with the law stated.

When we see an object clearly through a convex lens,

the former must be at or near the focus of the latter. Under these conditions the rays of light which are reflected from the object are rendered parallel by the lens. If both the object and the eye are stationary, the direction of these

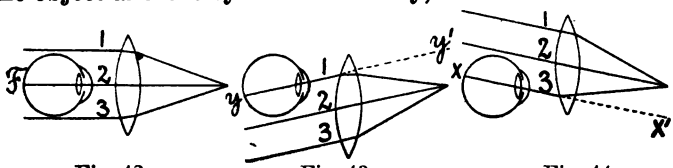


Fig. 42. Fig. 43. Fig. 44.

parallel rays will differ according as we move the lens up or down, that is, according as we look through the centre of the lens (Fig. 42), or through its upper or lower edge (Fig. 43 and 44). In each figure three pencils of such parallel rays are indicated by three lines, marked 1, 2, and 3. Not all of them will actually reach the eye, as the pupil is very small.

When we look through the centre of the lens, the narrow pencil 2 will pass through the pupil and stimulate the central portion (F) of the retina. As a result we see the object (say, a definite letter of the print) in the direction of this unbroken ray, that is, in its true direction.

When we look through the upper edge of the lens, the narrow pencil 1 will pass through the pupil and stimulate a lower, peripheral portion of the retina (y). Again we see the object in the direction of this unbroken ray, namely in the direction of y′. In other words, when we move the lens downward, the object will apparently move upward.

When we look through the lower edge of the lens, the narrow pencil 3 will pass through the pupil and stimulate an upper, peripheral portion (x) of the retina. We see the object again in the direction of the unbroken ray which caused the sensation, that is, in the direction of x′. In other words, when we move the lens upward, the object will have an apparent movement downward.

In a similar manner the object will apparently move to the left, if we move the lens to the right, and vice versa. This is clear from the same diagram and in accord with

the law stated. *The localisation of the different impressions is independent of any fixation-movements, because the eye must be kept steady. Otherwise the phenomenon will not occur.*

5. A Modified Form of the Local-Sign-Theory. For the reasons which we have advanced against the local-sign-theory, many of its present-day defenders admit that the monocular perception of direction cannot have been acquired by the *individual.* They insist, however, that it was acquired gradually by the *race* and then transmitted through heredity. *Thus the task which a trained psychologist cannot perform is put on the shoulders of our "less developed ancestors", possibly of the monkey tribe.* We leave it to the good common sense of the reader to judge whether this is an improvement upon the theory. And as to the monkey, we had better keep him out of the psychological laboratory. He is really out of place there.

CHAPTER IX

THE VISUAL PERCEPTION OF SPACE

II. THE MONOCULAR PERCEPTION OF DISTANCE

1. In our adult experience we perceive also the distance of objects in space monocularly. But this perception, unlike that of mere direction, is not immediate. It is based upon a number of criteria which previous experience has furnished us and is thus the result of various processes of association and sometimes of an explicit reasoning process.

The impression which an object makes upon the retina of one eye differs indeed with its distance. There is, however, nothing in this retinal impression which could be the basis for the immediate perception of the distance of the object seen. But the differences in the visual experiences, thus aroused, may be, and are, as a matter of fact, criteria by which we judge the distance of the object seen. All this will become clear as we proceed.

2. The first and main criterion of the distance of an object seen is its apparent size.

The size of the retinal image is inversely proportional to the distance of the object which causes it. This will be seen from the accompanying diagram (Fig. 45). One and the

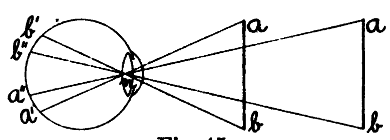


Fig. 45.

same object (ab) at one distance (from the optical centre n of the eye) causes a retinal image of the (linear) size a′ b′; at twice that distance, an image of half that size, namely a″ b″.

But this difference in the size of the retinal image is of itself no sufficient basis for the immediate perception of distance, as will become clear from the next diagram (Fig. 46). Here objects of different size (ab, cd, ef), but situated at different distances, cause a retinal image of the same size (a′ b′).

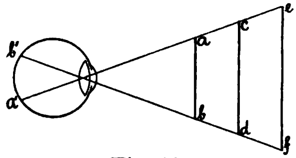


Fig. 46.

Our visual experience, too, changes with the distance of the object seen. Other conditions being equal, an object appears bigger or smaller according as it is nearer to, or further away from, the eye. Consequently we may also say that, *other conditions being equal, the apparent size of an object depends on the size of its retinal image.* When two men of equal height stand 10 feet away from us, both cause retinal images of the same size and both appear equally tall. When one of them moves to a distance of 20 feet away from us, we find he looks considerably shorter than his companion. From this it will be seen that *the apparent size of objects, seen monocularly, may become for us a criterion of their distance.*

3. It is only in the light of many experiences that the apparent size of objects is a criterion of their distance, and then only of their relative distance.

We said above "other conditions being equal". For it would be far from correct to say that the apparent size of an object depends exclusively on the size of its retinal image. In other words *the apparent size of an object is far from being an immediate datum of monocular vision.* Many experiences combine in determining our judgment concerning both the apparent size of an object and its distance. The following simple experiments are very instructive in this regard.

Experiment 78. Hold your right hand at reading distance and look at it with one eye. Then move your hand away from you as far as you can. The first diagram of this chapter will convince you that the retinal image of the hand is considerably larger in the first case than in the second. *Does your hand appear considerably larger at reading distance than at arm's length?*

How large the retinal image of your hand is you can find out readily by looking out of the window at a row of houses and then holding your right hand again at reading distance. The latter now covers actually a great number of houses. This means that the retinal image of the houses coincides with that of your hand. *Does your hand look as big as the houses?*

The simple fact is that familiar objects, situated in our immediate neighborhood, are judged to be of "constant size" no matter what the size of their retinal images may be (cf. Sanford, p. 196).

Experiment 79. Materials: A small red square; a large sheet of white or grey paper.

In the last experiment we found that *an object may have the same apparent size, though its retinal image varies considerably.* The present experiment will show that also the converse of this may occur: *an object may vary considerably in apparent size, though its retinal image remains unchanged.*

Make an ink-dot in the centre of the red-square and place it on a large sheet of white or grey paper. Hold the latter at reading distance and focus the ink-dot long enough to secure a good negative after-image of the square. Project the after-image on some other part of the white sheet, marked previously by an ink-dot or a small cross. You will find that the bluish-green after-image is of the same apparent size as the red square.

Now move the sheet of paper gradually away from you. Note that the after-image increases continually in apparent size. Bring the paper nearer and at last to less than

reading distance. Note how the after-image shrinks. Now project the same after-image upon a distant white wall and note that its apparent size is considerable. From these experiments we see that the apparent size of an object is not an immediate datum of monocular vision (cf. Seashore, l. c., pp. 42 sq.).

A subtle reader may object that this statement contradicts what we have said in the last chapter concerning the immediate perception of direction. For the latter, after all, means that the extension of an object in two dimensions is an immediate datum of monocular vision.

The answer is that the extension of an object in two dimensions is one thing, and its apparent size quite another. The former depends exclusively on the retinal area stimulated, the latter on a definite standard of comparison. A simple illustration will make this clear. No matter at what distance from us a man may be, if we see him at all, we cannot but see him extended in two dimensions. For he cannot possibly stimulate a mere mathematical point of the retina but only an area, and this area is the basis for our immediate perception of his extension in two dimensions. But does he appear big or small? That depends on our standard of comparison. Compared to a spaniel at his feet he is big; compared to a house in front of which he stands he is small. Similarly, as seen from a certain distance, he appears big or small, according as we compare him to himself, as seen from a greater or a shorter distance.

From all this it is also clear that the apparent size of an object cannot be a criterion of its distance, *unless we know beforehand what distance or extension in the third dimension is. We must know, moreover, how the object looks at a certain distance so that this appearance may serve as a standard of comparison.* In the case of an unfamiliar object, a familiar one placed side by side with it must serve as such a standard of comparison. Accordingly it is only the relative distance of an object which we determine with more or less accuracy by its apparent size under definite given circumstances. *Many experiences, therefore,*

must have preceded before we can make use of this criterion.

4. Under unusual conditions the apparent size of objects may also become a source of illusions.

The following experiments illustrate this.

Experiment 80. Materials: An opera glass or a concave lens. A spectacle lens such as is used by very short-sighted persons will serve the purposes of this experiment excellently.

View objects in the room or across the street with one eye through the wrong end of an opera glass or through a concave lens. Of course the latter must be held at a suitable distance from the eye for distinct vision. The immediate effect of this mode of procedure is that *the retinal image of the objects seen is considerably reduced in size.* (We cannot enter here into the reason for this; text-books of physics will supply the information.) As a further result one of three things may happen. Either the objects recede to a much greater distance or they look pigmy-like and unreal or both effects may be combined.

The reason for this is clear. The size of the retinal images of the objects seen is that which would arise, if the objects were really at a much greater distance from us. Of this, of course, we know nothing by introspection. But in consequence of this reduction of the retinal images the apparent size of the objects is also decreased. It corresponds to that which the objects would have, if they were viewed from such a greater distance. As we know their real size, one of the possible results is that the objects appear to be at such a greater distance. We know, however, also the real distance of the objects viewed. In virtue of this association they may appear pigmy-like and unreal, or both effects may be combined (cf. Sanford, p. 198).

Experiment 81. Materials: An opera glass or an improvised form of field glass, described below.

View objects in the room or across the street monocularly through an opera-glass, held in the ordinary manner. A

convex lens (of about 2″ diameter and 16″ focal length), held at some distance from the eye with one hand, together with a concave spectacle lens, brought very near the eye with the other hand, make a fairly good improvised field-glass. The immediate effect of both instruments is that *the retinal image of the objects seen is considerably increased.* As a further result these objects have the same apparent size which we are accustomed to experience when we are much nearer to them. As we know the real size of the objects, they do not appear unnaturally magnified but brought considerably nearer to us. At least most persons have this experience. When using the improvised field-glass we can see the objects actually move towards or away from us according as we hold the spectacle lens nearer to the eye or further away from it. A similar effect can be produced by turning the focussing screw of the opera-glass now one way now the other. Very near objects, thus seen, become alternately bigger and smaller (cf. Sanford, l. c.).

5. **The second criterion of the distance of objects seen with one eye is their apparent lateral displacement which results from the change in our standpoint, that is, from the fact that either we ourselves or the objects seen move in space.**

We have an exaggerated instance of this criterion when we are riding in a fast train. Looking out of the window we see the telegraph poles near the track move rapidly across our field of vision; one pole follows the other in quick succession. A conspicuous distant object, such as the steeple of a church on the horizon, remains practically stationary for quite a time, while trees and houses in the intervening space seem to move faster or slower according as they are nearer to, or further away from us.

Something similar happens, only to a less degree, whenever we change our standpoint, that is, whenever we move about in space. If our movement is voluntary and the objects viewed are stationary, we are fully aware that the lateral displacement of the latter is merely apparent. It

is due to the successive changes in our lines of visual direction. The degree of this apparent displacement, however, becomes for us a criterion by which we can estimate the relative distance of the objects thus seen.

When our standpoint is stationary and the objects seen are actually displaced in space, that is, when they are in motion, then the change in the lines of visual direction is more rapid in the case of nearer objects than in the case of objects further away from us. The degree of this change becomes again a criterion of the relative distance of the objects seen.

It need not be stated explicitly that the facts here described cannot possibly be a basis for the immediate perception of distance.

6. Other criteria of the distance of objects in space are: the degree of distinctness with which we see familiar objects or their parts; the distribution of light and shade; the relative vividness of colors and other color-effects, due to the distance of objects.

The various factors of the monocular perception of distance, here indicated, are made use of to great advantage by painters. All of them, except the changes in the natural colors of objects, can be readily ascertained by examining a good photograph of a landscape. In nature, however, they are not always unequivocal signs of the relative distance of objects. For they may also be due to the condition of the atmosphere. In a valley the latter has as a rule a dimming effect. On a clear day distant objects seen from a mountain or any elevated standpoint seem to be much nearer than on hazy days. Just such miscalculations show that our monocular perception of distance is far from being immediate.

7. Within very narrow limits also the effort which we experience in actively accommodating the eye for near objects can become an additional criterion of their relative distance.

Several times we had occasion to state that the eye is

constructed after the manner of a photographic camera. The phenomena of accommodation are best understood by means of this analogy. A camera must be focussed. When its lens is set in such a way that it gives a clear picture of a definite near object, all objects still nearer are out of focus, that is, they produce a blurred image on the plate. To focus the latter properly one of two things must be done. Either we must change the lens to one of greater refracting power, that is, we must use a more convex lens, or we must rack the lens further away from the plate. In photography the latter method is the more common. It is interesting to add that certain animals do the same thing: they instinctively move the lens of the eye forward or backward according as they fixate an object at one distance or another.

The human eye has the marvellous capacity of changing its lens by changing the curvature of the latter. This, too, is done instinctively and automatically by the appropriate contraction or relaxation of the ciliary muscle in the eye. The whole contrivance is somewhat complicated and need not be explained here. Suffice it to say that objects which are about 10 m. or further away from us are properly focussed—as well as they can be focussed in proportion to their size—when the ciliary muscle is at rest. In psychological terms this means that no effort is needed to focus such distant objects: we are *passively accommodated.*

For objects, however, which are situated within the distance of about 10 m. and 16 cm. from the eye we must *actively accommodate* the eye. That is to say, we must change the curvature of its lens by a suitable contraction of the ciliary muscle. Though this is done instinctively, we may become aware of the effort needed in doing so. Hence the degree of this effort may become a criterion for estimating the distance of the object clearly seen.

Though a marvel of teleology and of the utmost importance for clear vision, *active accommodation is practically a negligible factor of our monocular perception of distance.* For distances beyond that of a large room it does not come

into play at all. Within the limits of a large room it is almost entirely neglected by most persons. In fact it would require a rare appreciation of differences in muscular effort to base even a roughly accurate judgment of the distance of objects on this criterion (cf. Fröbes, l. c., pp. 287 sqq.).

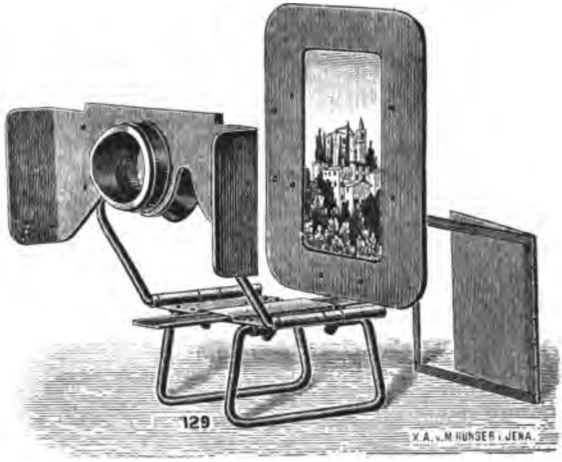


Fig. 47.—The Verant (from one of the publications of Carl Zeiss Optical Works, Jena, Germany).

8. The remarkable plastic effect of the optical instrument known as "the verant", is entirely due to the fact that it enables us to view photographs with one eye from that standpoint from which alone objects in nature have that appearance which they have on the photograph, namely from the standpoint of the camera which took the picture. Consequently the various criteria of distance in monocular vision can be made use of to an advantage which it is impossible to reach in viewing photographs without the verant.

Any picture, drawn in true linear perspective, gives us the impression of relief. This is due principally to the first criterion of distance. For *linear perspective is but another name for the effect of distance on the apparent size of objects.* In the case of photographs this impression of

relief is enhanced in a most remarkable degree when they are viewed through an optical instrument known as the verant. It is shown in the accompanying illustration.

To understand the reason for the remarkable plastic effect of this instrument it is important to note that it is only from a definite standpoint and only as seen with one eye that objects in nature have that apparent size which they have on the photograph. To a certain extent the same is true of the other effects of distance upon the appearance of objects. Hence the familiar fact that paintings of an art-gallery—in fact all pictures of sufficient size—are better viewed monocularly and from a definite standpoint. The main reason why small pictures, even photographs, fall far short of the plastic effect which we get in monocular vision of the objects themselves is that it is impossible to get the necessary standpoint. Hence the knowledge that we really handle a flat piece of paper is irresistibly forced upon us, even in monocular vision.

Of course the linear perspective of a small photograph is mathematically exact. But it must necessarily be held at the distance of distinct vision, that is, about 8-10 inches away from the eye. At this distance, however, the apparent size of any particular object depicted is far from coinciding with that which it has when we view the object in nature. To effect this, the photograph would have to be magnified, and that to a definite size. It is just such a magnification of the photograph—or more correctly, the corresponding increase in the size of the retinal images of the objects photographed—that is effected by the verant-lens. The latter is, moreover, so constructed that also the objects, depicted in the marginal portions of the photograph, cause no distorted retinal images. As a result we forget almost entirely that we handle a flat piece of paper and can see each object in turn under the identical visual angle which it has when we travel with the eye from object to object in nature without changing our standpoint.

If both the photograph and the verant-lens are correctly chosen, then the impression of relief is really surprising.

Though strictly monocular relief, it rivals the effect of the well-known stereoscope which depends on different factors altogether. Hence the verant should not be lacking in any psychological laboratory (cf. Fröbes, l. c., p. 283).

Experiment 82. Materials: A verant whose lens is properly chosen for the photographs to be viewed.

Verify the above statements. After you have ascertained the remarkable plastic effect of the instrument, tilt the photograph and note what will happen.

The tilting of a photograph of ordinary size makes little or no difference, when we view it (monocularly or binocularly) without the verant. No matter how we hold the picture, our standpoint differs too greatly from that which we ought to have. In proportion as we approach this condition, that is, in proportion as the photograph viewed is of the necessary size, its tilting makes a difference. But when we view it monocularly by means of the verant, the coincidence of the two standpoints is so striking in its effect, that the tilting of the picture changes our lines of visual direction considerably. The result is that we do not see the picture tilted, but the objects seen appear distorted.

CHAPTER X

THE VISUAL PERCEPTION OF SPACE

III. THE BINOCULAR PERCEPTION OF DISTANCE

1. The binocular perception of the distance of objects in space depends primarily on factors which are independent of any previous experience, namely (1) the slight lateral disparity of the two retinal images and (2) the fact that the two eyes are so co-ordinated as to act normally like one organ of single vision.

The binocular perception of distance, as we get it in our adult experience, depends on a great many factors. The latter may be divided into two classes, namely, those which are derived from previous experiences of various kinds and those which are independent of them. It is a matter of terminology which of the two we shall call primary or secondary.

The remarkable perfection of our binocular perception of distance is undoubtedly due to factors which are derived from previous experience. They are the same in binocular as in monocular vision, namely the various criteria discussed in the last chapter. If this perfection, then, is the measure of the relative importance of the various factors, then the said criteria are decidedly the primary ones.

If however we call those factors more important which render the purely visual perception of distance possible, even though it be very limited and imperfect, then the factors which are independent of any previous experience are undoubtedly the primary ones and those belonging to the former class must be designated secondary. And this is the terminology which we adopt.

For of the two considerations this is the more important one, namely how we come to see objects as extending in the

third dimension or as situated at different distances at all. This problem looks puzzling enough. For the retinal images of objects are of only two dimensions. If this problem can be solved satisfactorily without recourse to criteria derived from previous experience, then the important conclusion is that the binocular perception of distance is—within definite narrow limits—as immediate as the monocular perception of direction. It is, however, only after a careful consideration of the two above primary factors and their analysis into further component facts, experimentally verified, that we can establish this important conclusion.

2. The Slight Lateral Disparity of the Two Retinal Images. Normally we see objects simultaneously from two different points of view, namely that of the right eye and that of the left eye. It is owing to this fundamental fact that the two retinal images of the same trimensional object are slightly different from each other, and this difference is technically called lateral disparity. Waiving for the present the details of this lateral disparity, we shall ascertain the main fact by the following simple experiment.

Experiment 83. Materials: A small open box.

Look into the opening of a small box, held at arm's length straight before the eyes. Close the left eye (or preferably have an assistant cover it with a piece of cardboard) and note that the box, as seen with the right eye alone, looks like R in the accompanying diagram (Fig. 48). When the right eye is closed (or covered) in turn, the view which we get with the left eye alone looks something like L in the same figure. In other words, when we look at the box with the right eye alone, its distant wall seems shifted to the right; and shifted to the left, when we look at the box with the left eye alone. The retinal images we do not experience. But from what we know of the eye as an optical instrument we infer that the two retinal images are reversals of the two views. They are diagrammed at r and l respectively. There is, then, a

"lateral disparity" in the two retinal images of the same trimensional object.

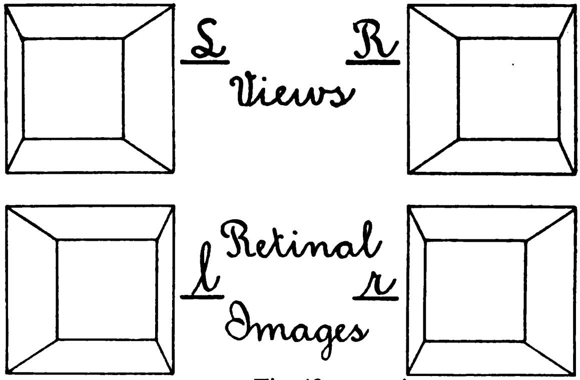


Fig. 48.

3. The two eyes are so co-ordinated as to act normally like one organ of single vision.

The co-ordination of the two eyes for the purpose of single vision is rather complex, resting on a number of further facts which have to be considered separately. We may treat of them under two main headings: *the co-ordination of the eye-movements,* and *the co-ordination of the two retinas.* These two kinds of co-ordination make it possible for the two eyes to act as one organ of single vision.

4. The movements of the two eyes are so co-ordinated that at any given time they have the same fixation-point, and this co-ordination is altogether automatic.

Whenever an object in space attracts our attention, our eyes move instinctively in such a way that the image of the object falls on the central area in each retina, the area of clearest vision. Both eyes have the same fixation-point. The possible points of fixation are many, in fact indefinitely many.

Suppose we hold this page straight and vertically before the two eyes at reading distance, then each individual letter on the page may successively become the fixation-point, and that without moving either head or book. If we want to

focus the letter situated at the centre of the page, our eyes automatically *converge symmetrically,* that is, both eyes turn inward through an equal angle, thus securing the common fixation-point. If we now wish to focus any one of the letters, printed in the same line to the right or to the left of the central one,—and that again without moving either head or page—we just as automatically converge the two eyes *assymmetrically.* That is to say, we move both eyes through an unequal angle, either both eyes inward or one eye inward and the other outward according to the position of the fixation-point.

We may also wander over the whole page in search of a definite passage which we wish to verify. Our eyes then execute a whole series of random movements until we strike the looked-for passage. But in all these movements, up or down, to the right or the left, both eyes act strictly together: at any given time they have the same fixation point.

If the object which attracts our attention, say the knob of a cane which a friend holds in his hand, moves slowly away from us—and it makes no difference whether the object moves in a straight or a curved line—the muscles of our eyes will automatically secure for us that degree of symmetrical or assymmetrical convergence which is necessary for maintaining a clear vision of the object.

By the time our friend is about 4 meters (or the length of a moderately large room) away from us, the convergence of our eyes has decreased to such an extent that they have practically a parallel position. If our friend moves still farther away in any direction whatever, our eyes maintain this parallel position while following his movements and thus secure for us whatever clear vision we can get of the knob of his cane.

In all this multiplicity of possible movements of the eyes there is one thing which we *normally* cannot do: *we cannot dissociate the eyes so that they have not the same fixation-point,* no matter where the object focussed may be

situated. It is only by artificial means that we can do so. But of this later.

This co-ordination of the eye-movements is effected by the appropriate contractions and relaxations of the various muscles attached to the eye-balls. These contractions and relaxations in turn are regulated by the system of afferent and efferent nerve-fibres connected with the two eyes. It is a matter of terminology whether we want to call these movements *instinctive* or *automatic* or *reflex*. Physiologically considered they conform to the type of the physiological reflex. We shall have more to say on this subject in a future chapter. Here it may suffice to say that such movements are carried out by an inherited mechanism of whose existence we are not even aware. Even after we are acquainted with this mechanism from what the physiologists tell us about its arrangement and working, this knowledge does not help us in the very least in bringing these movements about.

5. As a result of the co-ordinated eye-movements light reflected from the fixation-point will fall on the "fovea centralis" of each retina; light reflected from any other point in space will—according to its distance from the fixation-point and from the observer—fall either on "corresponding points" or on "laterally disparate points" of the two retinas.

We must now consider the lateral disparity of the two retinal images a little more in detail. For this purpose we must examine the relative positions of any twin points of the two retinas which are stimulated by light reflected from the same point in space. (We need not remind the reader explicitly that whenever we use in the following discussions the term "point" we always understand it in the sense of a "real point" in accordance with what we said in the last chapter.) Such twin retinal points are known as "corresponding" and "laterally disparate" points. We shall define them—for the present—not in terms of single or double vision but in terms of their relative positions

with regard to the two "foveae centrales". In other words we shall consider them merely as the result of the co-ordinated movements of the eyes, and the eyes themselves as two optical instruments built on the same general plan.

"Fovea centralis" is a little pit in the yellow spot or area of clearest vision in each retina, situated opposite the pupil of the eye. It is the centre of this little pit which is stimulated by light reflected from the fixation-point.

"Corresponding points" are any twin points of the two retinas which are situated at the same distance and in the same direction from the two foveas, so that if the two retinas were superimposed, the twin points would cover each other.

"Disparate points" are any twin retinal points which do not thus correspond.

"Laterally disparate points" are twin retinal points which are situated *on the same horizontal section* of the two retinas, but *not on the same vertical section,* that is, one more to the right, the other more to the left on the same horizontal section.

Experiment 84. Perform experiment 83 over again, but this time secure a definite fixation-point. For only then can we determine which points of the two retinal images, diagrammed above, are corresponding, and which are laterally disparate. The fixation-point must be a real point—a black cross, for instance, marked in a definite part of the object,—for without such real point to attract our attention our eyes will wander, following the contours of the object, and thus change the fixation-point continuously.

Let the fixation-point be the centre of the distant inner wall of the box, made conspicuous in the manner indicated. Hold the box as directed above. Viewing the box successively with the right and with the left eye, note that the two views you get of it are like those diagrammed in Fig. 49. The two retinal images, being reversals of these views, are accordingly like those marked in the lower portion of the figure.

The fixation-point (O) in the centre of the distant wall stimulates the centres of the two foveas (o and o′). The corners (A, B, C, D,) of the distant wall stimulate respectively the twin retinal points a a′, b b′, c c′, d d′. The points a and a′ are situated at the same distance and in the same direction from the foveas, and the same is true of the points b and b′, c and c′, d and d′. *These are "corresponding" retinal points.*

The corners (E, F, G, H,) of the opening of the box stimulate respectively the twin retinal points ee′, ff′ gg′, hh′. The points e and e′ are indeed on the same horizontal section of the two retinas, but they are not equidistant from the two foveas. The same must be said of the points f and f′, g and g′, h and h′. The whole square efgh is shifted to the right in the right retina, and the square c′f′g′h′ in the left retina is shifted to the left. If the two retinas were superimposed upon each other, the two inner squares would cover each other, but the outer squares would not. *The twin retinal points situated at the corners of the latter are "laterally disparate".*

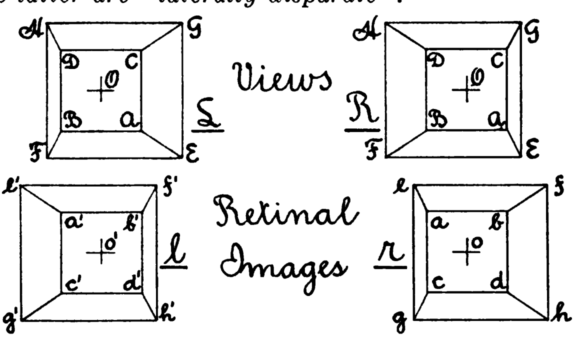


Fig. 49.

Experiment 85. **Secure a fixation point in the centre of the opening of the box, held as before. The point of a pencil, held in this centre will arrest the attention and thus the necessary co-ordinated movements of the eyes will be effected. For the rest proceed as before. The result is diagrammed in Fig. 50.**

In this experimental arrangement the corners (E, F, G, H) of the opening of the box will stimulate corresponding points, while the corners (A, B, C, D,) of the distant wall will stimulate laterally disparate points.

From this it will be seen that the same objective points which stimulated corresponding points in experiment 84, stimulate laterally disparate points in experiment 85, and vice versa. In both arrangements, however, *those points of the object which are situated in the plane of the fixation point, stimulate corresponding retinal points, and those objective points which are situated in a plane further away or nearer than the fixation point, stimulate laterally disparate points,* and the lateral disparity itself differs according as the objective points are situated before or behind the fixation-point. All this is clear from the two diagrams.

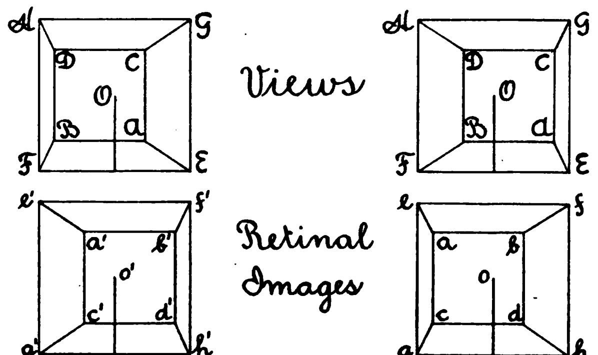


Fig. 50.

6. An object whose images fall on corresponding points of the two retinas or on points which are approximately corresponding, is seen single.

An object whose images fall on laterally disparate points will be seen double, if the lateral disparity exceeds a certain limit.

Normally all objects thus seen double are not attended to but completely ignored.

If the lateral disparity of the twin retinal points is slight, then the object whose images fall on these points, is not only seen single but localised before or behind the fixation-point; before, when seen with "crossed disparity"; behind, when seen with "uncrossed disparity".

We must now consider the co-ordination of the two retinal images for the purposes of single vision and the perception of distance. We shall not try to deduce this co-ordination from any of the laws which we have ascertained so far but shall rest satisfied with a mere description of facts which can be verified experimentally. They are expressed in the above four propositions, which we shall consider in turn.

7. The Fact of Single Vision with Two Eyes. If it were not for the sense of touch by which we can feel our two eyes, or for the fact that sometimes one of our eyes becomes unserviceable because of an intruding cinder, or for other similar experiences which force the knowledge upon us that we have two eyes,—from the mere fact that we see objects about us we would never even suspect that we see with two eyes, just as we would never suspect that we hear with two ears and smell with two nostrils.

The famous problem why we do not see things double, though we see them with two eyes, simply does not exist for us, any more than the other problem, equally famous, why we do not see things inverted, though their retinal images are inverted. These problems can arise in our minds only after we have found out—*aliunde*—that we have two eyes with such curious things as retinas within them, and that inverted images of objects are formed on them.

Nor do these problems admit of solution, any more than we can answer the questions why we do not see with our ears or hear with our eyes. We may say, of course, that such is the nature of the ear that it hears, and of the eye that it sees. But this is really no explanation of these facts, it is only another form of stating them: an

acknowledgement that they are ultimate and irreducible facts of our experience. In the same way *it is an ultimate and irreducible fact of experience that we normally see single with two eyes.* We express no more than just this ultimate fact of experience when we say that *the two retinal images, caused by objects in space, are so co-ordinated that the two eyes act normally as one organ of single vision, or are normally only two parts of one and the same organ of vision.*

While we cannot give any explanation of the fact, we can inquire into its conditions as well as into the conditions of double vision, if such a thing can be effected. Now we find—with the aid of geometrical constructions such as we briefly indicated in experiment 83—that all those objects are seen single whose images fall on corresponding retinal points, or on points whose lateral disparity does not exceed a certain limit. Objects, however, so situated that their images fall on retinal points whose lateral disparity exceeds this limit, are seen double. And this leads us to the second fact of binocular vision.

8. The Fact of Double Vision with Two Eyes. So completely is our attention occupied with things seen single that it comes to us as a distinct surprise that certain objects may be seen double, that in fact such *double vision is a normal incident of our daily life.* We shall ascertain the fact of double vision and the conditions under which it occurs by the following simple experiments.

Experiment 86. Let your fixation-point be a distant object. Hold a pencil at reading distance straight and vertically before your eyes. Without changing your distant fixation-point pay attention to the pencil. This requires some effort, as we normally pay attention to the object fixated. Under these conditions you will see the pencil double.

Now close your left eye (or have an assistant cover it with a piece of card-board) and observe that with the right eye you see the pencil to the left of the fixation-point.

Then close your right eye (or have it covered in a similar manner) and note that with the left eye you see the pencil to the right of the fixation-point. In technical language this is expressed by saying that you see the pencil double with "crossed disparity". This will become clear from the accompanying diagram (Fig. 51) in which F represents the distant fixation-point, F′ and F″ the two foveas stimulated by it, P the pencil, p′ and p″ the retinal points stimulated by the pencil. *These points are situated at equal distances from the foveas but not in the same direction,* p′ being to the right, p″ to the left of the respective fovea: *they are "laterally disparate points".* P′ represents the pencil as seen with the right eye, P″ the same as seen with the left eye.

The localisation of these double images is very inaccurate. We know that we hold the pencil at reading distance from

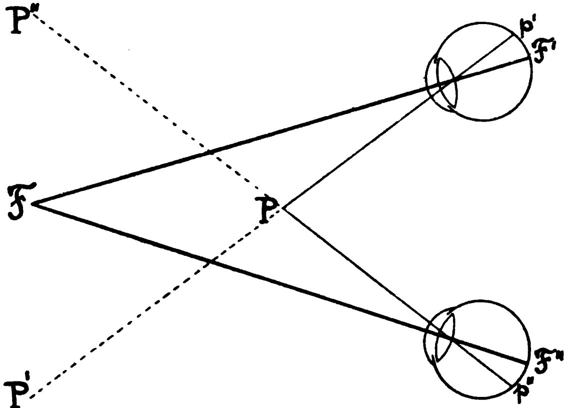


Fig. 51.

the eyes and in accordance with this knowledge we localize its double images much nearer than is marked in the diagram.

The same form of double vision, that is, with "crossed disparity", occurs in the case of every object in our field of vision which lies much nearer than the fixation-point. Such are, for instance, the bars of the window, when we

look at a distant house and a thousand other objects under similar circumstances.

Experiment 87. Let the fixation-point be a near object, say the forefinger of the right hand (F), held at the distance of about one foot from the eyes. Pay attention to a pencil (P), held at arm's length with the left hand. The pencil will again double, but this time we see it to the left of the fixation point with the left eye, and with the right eye to the right of the fixation-point. Ascertain this by closing the two eyes in turn.

The disparity of the two retinal points p′ and p″ is uncrossed, as is clear from the next diagram (Fig. 52) in which F′ and F″ represents the two foveas. The localisation of the doubly-seen pencil is again very uncertain and guided by the knowledge of the real position of the pencil.

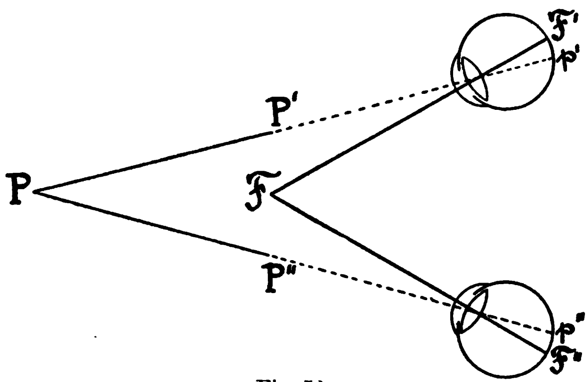


Fig. 52.

Hence P′ and P″ are seen further away than they are marked in the diagram.

The same form of double vision occurs frequently in our daily life, namely whenever the object stimulating disparate points, is further away than a near fixation-point.

Experiment 88. Perform experiments 86 and 87 over again, but this time move the pencil up and down, to the right and to the left, and in all sorts of random directions,

Provided we keep the fixation-point, as directed, we shall see the pencil in all these various positions double and that with crossed disparity in the arrangement of experiment 86, and with uncrossed disparity in the arrangement of experiment 87.

If we diagram the peculiar conditions of the present experiment we find that the double images may be both to the right or both to the left of the fixation-point. Accordingly *the essential feature of double vision with crossed and uncrossed disparity is this that in the former the lines of (indirect) vision cross, in the latter they do not cross.*

9. The Neglect of Things Seen Double. Though double images are of continual occurrence, the notable fact is that most persons never become aware of them: they completely ignore them. This neglect of things seen double has sometimes been called one of the curiosities of binocular vision. But really it is no curiosity at all. On the contrary it would be curious if we normally paid attention to them.

Why should we pick out double images as objects of attention, when we neglect a thousand other sensations to which we might pay attention? While you are reading this page, the clock in your room ticks as strongly as it does when you pay attention to it. In both cases, moreover, you actually hear it. But while your attention is fixed on the contents of this page, you hear the ticking as if you heard it not: you neglect it. And so it is with things seen double. If we are peculiarly interested in them, we become aware of them. Outside of the psychological laboratory, however, we are not interested in them.

As stated repeatedly, whenever an object in the indirect field of vision attracts our attention, we instinctively move our eyes in the direction of that object so as to get the clearest possible vision of it. As a result *the object fixated**

*Note: We say "the object fixated", not "the fixation-*point*"; the range of attention in binocular vision will be discussed in the next chapter, p. 206. (Cf. also pp. 233 sqq. and Stratton in Phil. Studien, Vol. 20, pp. 349-50.)

and the focus of attention normally coincide. The object thus fixated and attended to cannot by any effort of ours be seen double, and all objects which are seen double are outside the focus of attention. Hence normally we see them double, as if we saw them not: we neglect them.

From this it will be seen that the neglect of objects seen double is not so much a curiosity of binocular vision, as rather *one instance of the curious fact of attention.* We shall return to this important topic in a future chapter.

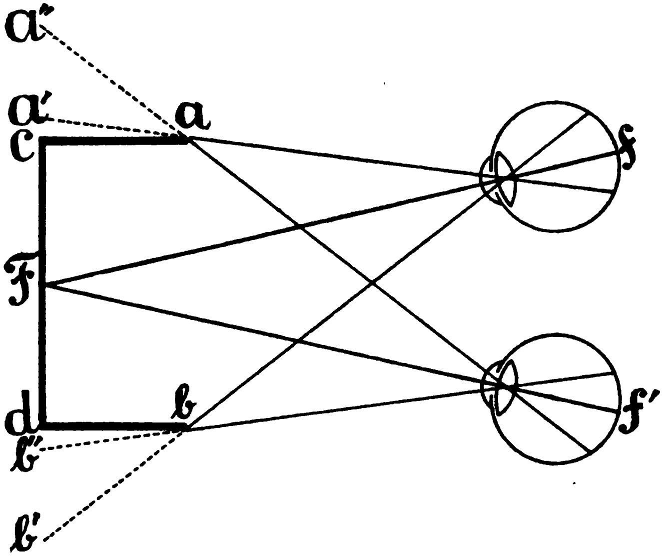


Fig. 53.—Diagram illustrating the localisation of points, seen with *(slight) crossed disparity.* *abcd* is a cross-section of the box; *F*, the fixation-point; *f*, the fovea of the right eye; *f'*, the fovea of the left eye. The opening *(ab)* of the box appears larger than its rear wall, and shifted to *a'b'*, when seen with the right eye alone; and shifted to *a''b''*, when seen with the left eye alone. *With both eyes it is seen, just where it is, at ab, BEFORE the fixation-point.*

10. The Localisation of Objects Seen with Slight Lateral Disparity. The last and most important fact of binocular vision is this. Objects or parts of the same object, which are seen with slight lateral disparity are—as a

matter of fact—localised before or behind the fixation-point, according as the slight lateral disparity is crossed or uncrossed.

In experiment 84 our fixation-point was the centre of the rear wall of the box. The square opening of the latter, as seen with the right eye alone, was apparently displaced to the left, and as seen with the left eye alone, apparently displaced to the right in the plane of fixation. Now focus the centre of the rear wall again but with both eyes simul-

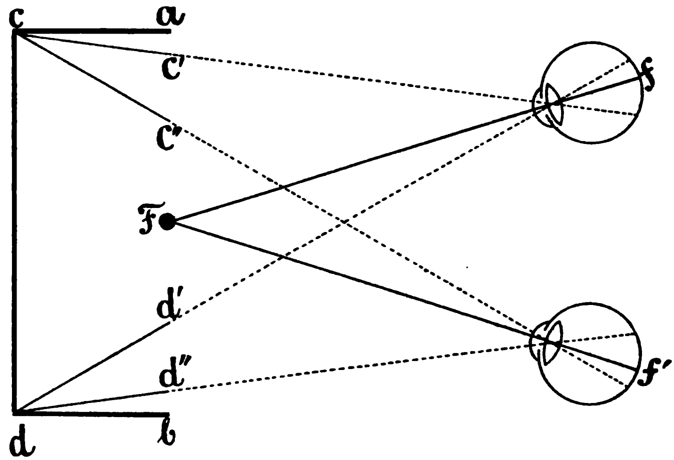


Fig. 54.—Diagram illustrating the localisation of points, seen with *(slight) uncrossed disparity. abcd* is a cross-section of the box; *F*, the fixation-point (the pencil); *f*, the fovea of the right eye; *f'*, the fovea of the left eye. The rear wall *(cd)* of the box appears smaller than its opening, and shifted to *c'd'*, when seen with the right eye alone; and shifted to *c''d''*, when seen with the left eye alone. *With both eyes it is seen, just where it is, at cd, BEHIND the fixation-point.*

taneously. Note that the opening of the box does not appear shifted either to the right or to the left in the plane of fixation, but we localise it—as a matter of fact—nearer than the fixation-point. (See Fig. 53.)

The slight disparity with which we see the opening is of the "crossed" kind. For if it were increased further, it would result in double vision with "crossed disparity".

We have only to bring the box nearer, thereby increasing the disparity, to experience actually such double vision of the opening.

In experiment 85 our fixation-point was the point of a pencil, held in the centre of the opening of the box. Then the square distant wall, as seen with the left eye alone, was apparently displayed towards the left in the plane of fixation, and towards the right, as seen with the right eye alone. When we focus the pencil-point simultaneously with both eyes, the distant wall is not displaced either to the right or to the left in the plane of fixation, but it is—as a matter of fact—localised behind the fixation-point. (See Fig. 54.)

The slight disparity with which we see the rear wall is of the "uncrossed" kind. For if it were increased further, it would result in double vision with "uncrossed disparity". When we hold the box too near the eyes, we actually experience this kind of double vision.

Now the same two empirical rules of localisation hold with regard to all trimensional objects in nature, or parts of one and the same object, which are seen with crossed or uncrossed disparity, provided the latter is neither too great nor too slight. *Accordingly the slight lateral disparity of the two retinal images is—as a matter of fact—one of the factors of our normal perception of distance or the third dimension.*

CHAPTER XI

THE VISUAL PERCEPTION OF SPACE

III. THE BINOCULAR PERCEPTION OF DISTANCE

(Concluded)

1. **The Stereoscope.** If the slight lateral disparity of the two retinal images is really a factor of the perception of distance, then it should be possible to enhance by its means the impression of relief which is obtained by viewing photographs of trimensional objects. It would only be necessary to take two photographs of the same trimensional object or sets of objects, one from the standpoint of the right eye, the other from that of the left eye, and to present these two slightly different views each to its proper eye for binocular combination. Provided the latter can be successfully obtained, the result should be the same as when we view the trimensional objects themselves with two eyes. Now this is actually the case.

Two photographs, thus made and mounted either singly (RR′ and LL′ in Fig. 56) or side by side (RR′ and LL′ in Fig. 55) are known collectively as a stereogram. The optical instrument which renders their binocular combination easy—though it is not necessary for such a combination —is known as the stereoscope. The two most common forms of the latter are 1) *the prism-stereoscope of Brewster,* diagrammed as to its essentials in Fig. 55, and 2) *the mirror-stereoscope of Wheatstone,* diagrammed in Fig. 56. The letters RR′ in both diagrams denote the view of the right eye, LL′, that of the left eye, RL, the virtual combined image of the two views. F in both views stands for the common fixation-point, F′ for the fixation-point in the combined virtual image. P and P′ are the refracting prisms (or prismatic lenses), M and M′, the reflecting mirrors; bb′ is a bar, preventing each eye from seeing

the view of the other. The unbroken lines denote the actual paths of light; the dotted lines, the lines of direct vision and projection.

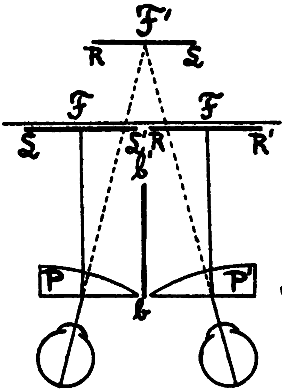


Fig. 55.

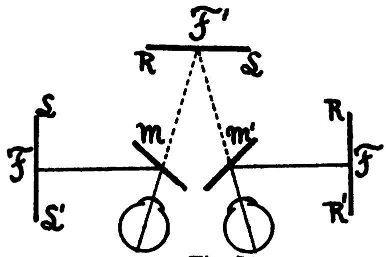


Fig. 56.

The most perfect form of this optical instrument is *the verant-stereoscope,* constructed by the Zeiss firm in Jena, Germany. It combines all the features of the verant with those of the stereoscope (and is a rather expensive instrument). Provided we have stereograms which really fit the accurate conditions of this instrument, the latter enables us to view objects binocularly from the identical two standpoints which we have when we look binocularly at trimensional objects in nature. *Thus, all the factors of the binocular perception of distance are made use of to the greatest advantage.*

For the purposes of our discussion an ordinary stereoscope, such as is usually supplied by dealers, amply suffices. For it is really not the remarkable joint effect of all the factors of stereoscopic vision which interests us now. On the contrary *it is desirable that we should eliminate, if possible, all its factors except the lateral disparity of the retinal images.* If this can be done successfully we can ascertain whether the lateral disparity is of itself sufficient to *create* the sensory impression of relief. If, however, it is impossible to eliminate all the other factors, we should

like to know *how much of the effect is due to the lateral disparity and how much to the other factors.* The following experiments are devised to answer these questions.

Experiment 89. Materials for this and the following experiments: An ordinary stereoscope.

Unscrew the base-board of the stereoscope so that only its hood with the two prisms is left. The handle should then be attached to the base of the hood. Or, still simpler, cut off part of the base-board, as indicated in the accompanying illustration (Fig. 57). *With the instrument in this form we can view directly all the stereograms contained in this book.* Thus the laborious task of preparing the necessary stereoscopic slides is avoided. Nor is the instrument spoiled. For we can use it also for viewing any photographic slides. One of our hands will serve the purposes of the absent slide-holder.

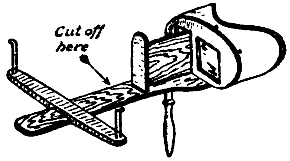


Fig. 57.

With the right hand adjust the prisms before your eyes. If you wear spectacles, do not remove them. With the left hand hold the following stereogram (Fig. 58) before the two prisms in such a position and at such a distance that you can easily combine the two views and see every detail clearly. Now *focus the cross steadily* and describe your experience.

By focussing the cross steadily we gain two advantages. First of all *we know precisely which points in the two views are corresponding and which are laterally disparate.* For the conditions of the present experiment are in this regard exactly the same as those of experiment 84. Each eye gets the same view of the box which it had in the latter experiment. Of course we may also wander with our eyes over the whole box, following its contours, or fixating suc-

cessively any of its corners. The plastic effect will be identically the same, no matter which point we focus, and this effect will in each instance be due—at least partly—to the lateral disparity of the retinal images. But we do not know any longer which points are corresponding and which

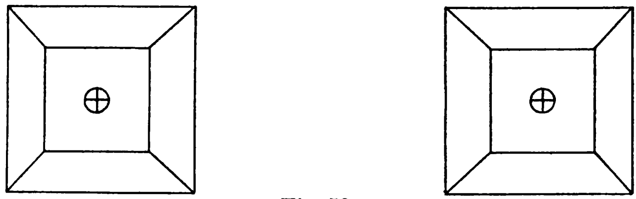


Fig. 58.

are laterally disparate, nor whether the disparity is crossed or uncrossed. We should have to figure this out for every individual fixation-point.

The second advantage is even greater. *We exclude all eye-movements and that in a manner in which we really can do so successfully.* When following the contours of an object, our fixation-movements are very jerky and inaccurate, but when we fixate a stationary real point—here the cross—we can do so with remarkable accuracy. Consequently *in the present experiment fixation-movements and the sensations arising from them are entirely eliminated as factors of the perception of distance.*

Besides the lateral disparity of the retinal images, then, there is only one factor left, namely *linear perspective.* This we cannot eliminate. But we can ascertain how much of the plastic effect is due to this factor. *Just close one of your eyes. Now only linear perspective remains. For it is present in each of the two views. Then open the eye again and note the difference in the sensory impression of relief.*

Experiment 90. Proceed in exactly the same manner in viewing the following stereogram (Fig. 59). Focus the pencil-point in the centre of the square opening of the box, as we did in experiment 85. No comment is needed on the results of the present experiment.

Fig. 59.

Experiment 91. Before combining the two views of the following stereogram (Fig. 60) by means of the stereoscope, try to make out what the object represented, and the spatial arrangement of its parts, may be. In all probability you will see nothing but a meaningless pattern of straight lines on a flat piece of paper. In other words, the linear perspective of the object is in this instance ineffective: it causes no perception of distance. The reason for this is, that *the object represented is a very unusual one.*

Now observe the stereogram by means of the stereoscope. *Avoid eye-movements by fixating steadily any particular corner of the object.* Note the remarkable impression of

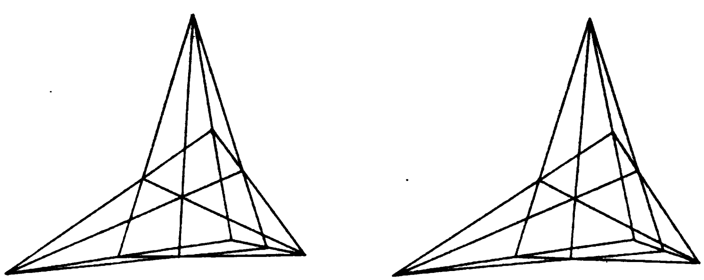


Fig. 60.—(From J. Martius Matzdorff, Die interess. Erscheinungen der Stereoskopie; Winckelmann & Söhne, Berlin.)

relief and that it is due exclusively to the lateral disparity of the retinal images, at least when you combine the two views of the stereogram for the first time.

Experiment 92. Can you make out without the stereoscope what object is represented in the next stereogram? If you have read all the preceding chapters, *the object*

should be very familiar to you. But its position is a most unusual one. The result is that its linear perspective is ineffective.

Now examine the stereogram by means of the stereoscope and *avoid eye-movements by fixating steadily any particular corner of the object as it appears now.* You will be surprised to find that the flat geometrical pattern turns

Fig. 61.—(From J. Martius-Matzdorff, l. c.)

out to be our "color-octahedron". In this instance again the plastic effect is due exclusively to the lateral disparity of the retinal images, at least when you combine the two views of the stereogram for the first time.

Experiment 93. In the following stereogram (Fig. 62) *there is absolutely nothing even to suggest linear perspective. By focussing the bold-type letter of the combined print we exclude all eye-movements. Only the slight lateral disparity is left to account for the impression of relief.*

WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?

Fig. 62.

The twin bold-type letters of the right- and left-hand prints stimulate the foveas of the two eyes. From this the student should be able to foretell whether the combined letters of the first line will be localised before or behind the fixation-point.

Experiment 94. If the twin bold-type letters in the following stereogram (Fig. 63) stimulate the two foveas, where will the letters of the second and fourth lines be localised?

WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?
WHERE?	WHERE?

Fig. 63.

Experiment 95. View the last two stereograms again and *pay particular attention to this whether the five lines are straight or curved.* Can you suggest any reason why the letters of any particular line should be arranged in zigzag fashion?

2. The perception of the third dimension, in so far as it is really due to the slight lateral disparity of the retinal images, is a primitive and irreducible fact of binocular vision in the nativistic sense and is independent of any criteria which are supposed to guide us in this perception.

That the slight lateral disparity is a factor of the perception of the third dimension is admitted by all. The question now naturally presents itself: Why is an object localised nearer or further away than the fixation-point, when its images fall on laterally disparate points of the two retinas?

Our answer is that *the twin retinal points, thus stimulated, are congenitally co-ordinated for this purpose, just as the eye is congenitally made to see, and the ear to hear.* This contention is known as "nativism." We emphasize again, as we did in the eighth chapter, that this doctrine does not necessarily imply any such thing as "Kantian forms." At any rate, *as we understand the doctrine, it simply means that the sensory impression of the third dimension or of distance—in so far as it is really due to the slight lateral disparity of the retinal images—is an*

immediate and irreducible datum of binocular vision. In other words, *we have a primitive and immediate perception of distance* which forms the basis for the highly developed perception of distance, as we get it in our adult experience.

We can establish the nativistic doctrine only by examining and testing the local-sign-theory of the empiricists.

3. **The Local-Sign-Theory of the Empiricists.** The empiricists contend that our binocular perception of distance is in its entirety gradually acquired. In other words, it does not depend *directly* on the slight lateral disparity of the retinal images but *indirectly* only. Our eyes are normally in constant movement, thus changing their common fixation-point continually. If it were not for these eye-movements, we would not avoid double vision. For all objects—it is claimed—whose images fall on laterally disparate points of the two retinas are seen double. Normally we ignore all objects thus seen double, precisely because of the continual eye-movements. *When, however, an object thus seen attracts our attention, we instinctively converge our eyes upon it* and then we see it single. If this object is *nearer* to us than the former fixation-point, we must *increase the convergence* of our eyes, and more so in proportion as that object is nearer to us. If the object which attracts our attention is *further away* than the first fixation-point, we must *relax* the eye-muscles so as to *lessen the convergence* of the eyes.

Though these movements occur instinctively, we become aware of them, when they occur, that is, we experience kinaesthetic sensations. We become also aware of the relative extent of these movements which are necessary to avoid double vision, that is, we discriminate between the various kinaesthetic sensations. *Thus the movements of convergence (and accommodation) and the sensations which arise from them become criteria or "signs" for us by which we judge the distance of the object seen.* It is thus that the perception of distance is originally acquired. In one

word: *these eye-movements are gradually worked out into a system of "local signs."*

Once this system of "local signs" is firmly established, that is, in adult life, we judge the distance of objects even in the absence of the actual movements of convergence. *The mere stimulation of definite twin retinal points arouses the memory image of the corresponding movement and we remember the effort needed to execute it, and in virtue of this association we localise the object before or behind the fixation-point.*

4. Experimental Tests of the Local-Sign-Theory. We do not deny that such kinaesthetic sensations occur, nor that they may become criteria or secondary factors of our binocular perception of distance. In the light of the subsequent considerations, however, *it is doubtful whether they have at any time much to do with our binocular perception of distance.* Be this as it may, *we deny the main contention of the empiricists that our visual perception of distance is thus originally acquired.*

First of all, it is not true that all objects or parts of objects, whose images fall on laterally disparate points are seen double. This is true only when the lateral disparity exceeds a certain limit.

Nor is it true that we ignore double images only because of the continual movements of the eyes.

We have forestalled both contentions in all our experiments with the stereoscope (Exp. 89—95). In all of them the lateral disparity was slight and we experienced no double images; in all of them eye-movements were excluded with fair accuracy. Even if occasional slips of fixation occurred, they were never such as are postulated in the local-sign-theory, that is, they never amounted to our following the contours of the object seen. In spite of that we had not only single vision but localised the various parts of each object before or behind the fixation-point in accordance with the laws stated in the last chapter.

Experiments of Helmholtz and Others. If additional

evidence on these points be desired, *Helmholtz and others have performed similar experiments with eyes in a fixed position in such a way that the stereograms were illuminated only momentarily by means of an electric spark.* Now this illumination is so infinitesimally short that no eye-movements can possibly occur while the light, reflected from the stereograms, actually reaches the eyes. And the result was that, whenever the lateral disparity did not exceed a certain limit, the impression of relief was there. The reader who is interested in performing these experiments for himself will find a detailed description of them in Helmholtz's Phys. Optik., pp. 710 and 890 sqq.

If it be claimed that in all such experiments with fixed eyes we are guided by *memory-images of the necessary eye-movements,* there is a simple way of settling that claim. *Simply perform the above experiments (89-95) over again with your attention concentrated on one thing: to discover these memory-images, if they be there, and to find out whether they really guide you in localising objects in the third dimension. Can you verify this?* In the case of all other criteria of distance we can verify them, and we have verified them under appropriate experimental conditions. *In the case of this supposed criterion not even the most trained psychologists have ever succeeded in discovering it.*

We have, moreover, *positive experimental evidence that considerable eye-movements, and particularly those of convergence, occur without our even becoming aware of the fact.* The following simple experiment—a variation of one described by Sanford, p. 200,—will convince the student of this.

Experiment 96. Make two ink-dots on the window, one before each eye. Their distance from each other should be about 2 inches, that is, *a little less than the distance of one eye from the other.* Now, standing at reading distance from the two dots, focus some object across the street, but pay attention to the dots. The result of this will be that your eyes assume gradually a definite position of con-

vergence which approaches the parallel position. As a further result the two dots will be each seen double. In other words, you see now four ink-dots instead of two.

Now try to combine binocularly the two middle ones, so that you see only three ink-dots. Once the binocular combination has taken place, ignore the two outer dots and focus the middle (combined) one steadily. This, of course, means that *you must control your eye-movements.* With a little practice you can do so readily, *provided you guide yourself, not by the sensations of eye-movements, but by the visual sensation resulting from them: the single vision of the combined dot.*

After these preliminaries proceed as follows. Take a small, black cardboard in your hand and combine the two dots binocularly as before. When you see them steadily as one, cover both dots with the black card-board or, preferably, have this done by an assistant. Under these conditions the single vision of the combined dot can no longer guide you in controlling the movements of convergence. *Try to do so by means of the effort you must make to keep the eyes fixed in the same position of convergence. Pay particular attention to this effort and to eye-movements, if any such should occur.*

After about a minute remove the card-board and *note whether you see one dot, as before, or two instead.* The question is not whether you can combine them readily again, but whether, *immediately upon the removal of the card, you see two or one.* If you see two, this means that your eyes have moved and you can judge the extent of their movements by the relative separation of the two dots.

Most persons upon performing this or similar experiments, find that their eyes have moved considerably without their being even aware of the fact. That is to say, *they do not become aware of the fact because of kinaesthetic sensations arising from the movements, but from the subsequent fact of double vision.* Find out for yourself and describe your own experience.

Perhaps you became dimly aware of the fact that your

eyes moved. If so, *could you judge in what direction and to what extent? If you cannot, then the local-sign-theory has once again failed to stand the test of experiment.*

It is to be noted that it counts for little, if sometimes we succeed in keeping the eyes in a fixed position, especially if the latter happens to be a convenient one. The point against the local-sign-theory is that considerable movements occur without our being aware of the fact, and that in no case are we able to judge the extent of the movements with that remarkable accuracy which is postulated in the local-sign-theory.

Nor will it save the theory to say that at present—that is, in adult life,—we are indeed unable to notice and discriminate between such delicate eye-movements, but that *we did so, when we elaborated the system of local-signs: as babies in the cradle.* Whatever such an assumption may be worth, it has surely nothing to do with experimental psychology.

Further Experiments. Several other experimental tests of the local-sign-theory might be mentioned here. It may suffice to state that the binocular combination of stereograms can be effected not only with *convergent* but also with *parallel,* and even with *divergent* eyes. The impression of relief is in every instance the same. The lens-stereoscope of the Zeiss firm with its adjustable oculars makes all three modes of viewing stereograms possible. Several experimental devices for doing the same are described by Sanford, pp. 289 sqq., to which the reader is referred. When we view a stereogram with actually divergent eyes—a thing which under normal conditions is simply impossible for us—surely the sensations arising from such unusual movements cannot possibly guide us in the perception of distance. *All that eye-movements—normal as well as abnormal—do for us is this: They secure the lateral disparity of the retinal images. This secured, the plastic effect is immediate.*

5. The Effect of Practice, Expectation, and "Good

Will" on Stereoscopic Vision. Some readers, in spite of repeated trials, may not have succeeded in seeing the stereograms used in Experiments 93 and 94 plastically. Others may have ascertained that the different lines appear to be at different distances, but they fail to see the zigzag arrangement of the single letters in each line. To such readers the only advice that can be given is: Try again and do so persistently! For in this, as in all other useful accomplishments, the old adage holds: "Practice makes perfect."

While this may be a bit of practical advice, what about the value of our experiments with the stereoscope as tests of the nativistic contention? If plastic vision may be acquired by practice, how can it be said that it is due to the congenital co-ordination of the twin retinal points stimulated? *What is congenital is not acquired by practice, and conversely, what is acquired by practice is thereby proven not to be congenital.*

Moreover it would really seem as if *our "good will" helped us considerably to see what we did not see before.* When we viewed the less difficult stereograms by means of the stereoscope, we saw them plastically, and other observers say that they see also the stereograms of experiments 93 and 94 plastically. They describe to us the different distances at which the single lines and letters appear. *Accordingly we expect to see the lines and letters at the same distances, and our imagination does the rest.*

Now there is a good deal of truth in all this but it is far from invalidating our argument. *Practice is necessary for a beginner to secure the artificial conditions of our experiments.* He must learn to co-ordinate the movements of fixation with those of accommodation in a rather unusual manner. When we use the stereoscope we must do what we normally never do: *we must accommodate the eyes for reading distance and at the same time fixate some point which, as a rule, is situated considerably beyond reading distance.* The fixation-movements differ, in fact, with the concrete conditions under which any par-

ticular stereogram is viewed. Hence the fact that at first when the binocular combination takes place, the object viewed looks anything but distinct. The eyes are not yet sufficiently accommodated for reading distance. Of course a stereogram will be seen plastically only when the unusual co-ordination of fixation- and accommodation-movements is effected. *This co-ordination of eye-movements must be learned and it can be learned only by practice.*

If practice can do more, and do it independently of the congenital co-ordination of the twin retinal points stimulated, there is a simple way of settling this claim. *Combine binocularly two prints made from the same plate, say, two copies of the same magazine-article.* Practice and good will will never help us to see them any other way than flat.

But if the effect is immediate, why should our plastic vision *improve* with practice so that we now see the zigzag arrangement of the single letters which we failed to see before? *The answer is that in the performance of this experiment we experience what occurs to us a thousand times over in daily life.* Details of a new object which are at first overlooked—not explicitly attended to—are appreciated gradually. If the object is a rather unusual one, we frequently need somebody else to call our attention to such details, and then we wonder how we could have missed them. *Here again, as in the case of neglected double vision, we have to do, not with a peculiarity of double vision, but with the curious fact of attention,* which dominates our whole conscious life.

Our imagination and expectation, too, help us to see what otherwise would pass unnoticed. *This again is but another phase of the curious fact of attention. Our memory images, expectations, and previous knowledge of all kinds are universally of paramount importance in determining the direction of our attention.* An expert geologist and an ordinary traveller see the same embankment which they happen to pass. The latter has seen nothing of what the geologist has seen, and vice versa. Each, however has seen

what is most in conformity with his previous knowledge, interests and expectations. We shall revert to this topic in chapter XIII.

Moreover, there is such a thing as ignoring one eye, though both eyes are kept open. Many squinters habitually ignore one eye. For they cannot execute the proper eye-movements to avoid double vision. Those who work a good deal with the microscope in the orthodox way—that is, who observe with one eye, while the other is left open,—acquire a similar habit. And we all occasionally do the same thing, namely, whenever one eye is rather in the way of seeing clearly what we are interested in or when one eye is notably weaker than the other. Now *the same thing may happen to a beginner, when he uses the stereoscope,* particularly if he is called upon to view such unusual stereograms as those of experiments 93 and 94. The difficulties which he experiences in the use of the stereoscope may result in his simply ignoring one eye. If he does, of course, the stereograms will look flat. *Here again we have to do with one of the curiosities of attention.*

No one will deny that color-qualities are immediate data of our visual experience and yet practice has a great deal to do with our sensitiveness to colors. Without considerable experience and practice no one is able to make the fine discriminations between various color-tones, tints and shades, which are made by an expert worker in mosaic. *Practice sharpens not so much our senses as our attention.*

These answers suffice to assign the proper role to practice, good will and imagination in the performance of our test-experiments. The difficulty based on these factors leaves our argument for the nativistic contention untouched.

6. The Limitations of Our Immediate Perception of Distance. Our normal perception of distance, in so far as it is due directly to the lateral disparity of retinal images, is immediate, but it is limited in various ways.

The first limitation arises from the position of our two eyes. They are, as an average, about 64 mm apart. Hence

the difference in their viewpoints is not very great. As a result of this many objects in nature cannot possibly cause retinal images whose lateral disparity is sufficient to be a basis for the immediate perception of their extension in the third dimension.

Experiment 97. Perform experiment 83 over again with this difference that an assistant holds the small box before your eyes, first at reading distance, then a foot further away, then two, and so on. Examine the box in each position first with the right eye alone, then with the left. We shall find that the difference in the two views of the box decreases continually with its distance. After some time they are practically alike. This means that the retinal images of the box fall now both on corresponding points. At a still greater distance, in fact, the whole box becomes a single fixation-"point" for both eyes. Under these conditions we cannot possibly have an immediate perception of the extension of the box in the third dimension.

Even after the whole box has become a single fixation-"point" for both eyes, we may still have an immediate perception of *its distance from other objects,* situated before or behind the box, provided these objects cause retinal images with sufficient lateral disparity. But this disparity again decreases, the further the various objects surrounding the fixation-point are away from us.

When our fixation-point is about a mile away, objects still further away, no matter how enormous their distances from one another and from the fixation-point may be, cause retinal images which are practically alike. In other words, the twin retinal images stimulated by them are practically all corresponding. *Hence the perception of the distance of all objects farther away from us than about a mile, cannot possibly be immediate.* With regard to them we depend exclusively on the secondary factors of the perception of distance, that is, we judge their distances by the same criteria on which we rely in monocular

vision. *It should be added that—practically at least—the same is true of all objects farther away from us than about 250 meters, that is, about three city blocks* (cf. Sanford, p. 260).

Another, and still greater limitation of the immediate perception of distance arises from the limited range of our attention. Normally we pay attention only to the objects which are situated within the immediate neighborhood of our fixation-point. Of course, we can, and do, sweep our eyes over the whole field of vision and thus view successively a great number of objects. For our immediate perception of distance, however, only those objects come into consideration which, in any definite position of the eyes, can be attended to.

What we *have* seen, *has* been a matter of immediate perception and is now a matter of memory. Similarly what we *shall* see in the future positions of the eyes, *will* be a matter of immediate perception but can now only be a matter of *expectation.* And it is thus that *our memories and expectations are inextricably mingled with the data of our immediate experience.* This is true not only of our binocular perception of distance, as we get it in adult life, but of all sense-perceptions. We shall return to this, when discussing the important topic of sense-perceptions in general.

This seems to be the proper place to explain a peculiarity in the terminology which we have used all along in these chapters on the visual perception of space. We have distinguished between the *immediate* and the *mediate perception* both of distance and direction. The former term, as we have understood it in these chapters, is simply synonymous with *sensation.* Accordingly when we said, for instance, that the binocular perception of the third dimension, due directly to the lateral disparity of the retinal images, is immediate, this means: *We have strictly a sensation or a sensory experience of the third dimension under these conditions.* In other words, it is not what we shall call in a future chapter a sense-perception in the technical

sense. It is for this reason, too, that we have entirely separated the subject of visual space perception from the general subject of perception or sense-perception. Inasmuch, however, as secondary factors or criteria enter into our space-perception, the latter is what is known technically as a perception and not a sensation.

Within the said two limits our immediate perception of distance is remarkably accurate for objects in our immediate neighborhood.

Experiments of Helmholtz and Others. Helmholtz experimented with three needles, fastened on three blocks of wood. They were placed on a table in such a way that he could not guide himself in his judgments of distance by the movements of the blocks but had to rely exclusively on his sensory impression, due to the lateral disparity of the retinal images. When the needles were in the same plane directly before him at a distance of 34 cm., it sufficed to move one of them half a millimeter before or behind the others, to be thus appreciated (Helmholtz, Phys. Opt., p. 790). Other investigators have carried out similar experiments with results which were equally remarkable. Prof. Tschermak has devised a special instrument, known as the "needle-stereoscope," for the performance of this interesting experiment (cf. Beihefte z. Z. f. Angew. Psychologie, Heft 5, 1912).

CHAPTER XII

THE VISUAL PERCEPTION OF SPACE

IV. THE BINOCULAR PERCEPTION OF DIRECTION

1. The So-Called "Cyclopean Eye." Our two eyes act strictly together as one organ of single vision. We have discussed the significance of this fact for the perception of distance, but it bears also on the problem as to the direction in which we see objects with both eyes.

We stated in chapter VIII (n. 2) that *the direction in which we perceive objects in space monocularly depends on the retinal points stimulated.* This was further explained by saying that *we refer every retinal impression back into space along the line of the unbroken ray which*

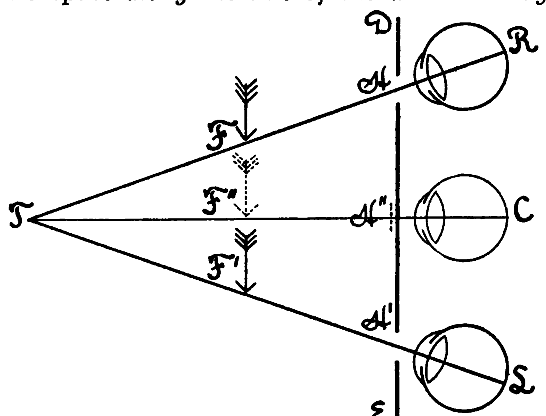


Fig. 64.

causes, or would normally cause, the impression. The latter statement must be somewhat modified or rather *supplemented,* when we speak of the direction of objects seen *binocularly.* The appended diagram (Fig. 64) will help the student to understand the problem.

Let T represent a distant tower, our fixation-point, R the *fovea centralis* of the right eye, and L that of the left eye. RT is the line of visual direction for the right eye; LT that for the left eye in accordance with what we stated in chapter VIII. *Now in what direction do we see the tower when we look at it with both eyes?* in the direction RT or in that LT?

As a matter of fact we do not see the tower in either of these two directions, but in the direction CT, that is, *in the direction which is determined by T and the fovea centralis of an imaginary Cyclopean eye C,* situated midway between the two eyes. Accordingly *the two lines of visual direction RT and LT become in binocular vision one line of identical direction, namely, CT.* Furthermore not only T is seen in the direction CT, but also *all other objects situated along the two lines RT and LT are seen in the identical direction, namely, CT.* The following experiments will show this.

Fig. 65.

Experiment 98. Prepare a piece of card-board like that in the accompanying diagram (Fig. 65). H and H′ represent two holes which should be uniformly cut at the actual distance of the two eyes. (Mere pinholes will do.) If you wear spectacles, measure the distance from the left-hand side of one lens to that of the other.

Rest this card-board after the manner of an extra pair of spectacles on the nose so that the two holes are exactly in front of the pupils of the two eyes. This cardboard (DE) with its two holes (H and H′) is also indicated in Fig. 64. Now look through these holes at an object on the distant horizon, say T. The eyes will then assume a parallel

position. (In the diagram the eyes had to be drawn as converging, because T is so near to R and L, whereas it ought to be at infinite distance. It should be added, however, that *the law of identical directions holds also for converging eyes.)*

Now note first of all that we do not see two holes in the card-board but only one, and this is situated at H″ (in Fig. 64), midway between the two real holes H and H′. In other words, it is just at the root of the nose before the imaginary Cyclopean eye C. We see the tower in the direction TH″, or what is the same, in the direction TC.

Holding the card-board with the left hand, move the forefinger F of the right hand from right to left before the face. Be sure to keep the distant fixation-point. Note that you see the finger move in the direction of the dotted arrow F″. When it has passed, it appears a second time in the same place and moves in exactly the same direction from right to left.

Note further that when you see the finger for the first time straight ahead of you at F″, it is really straight before the right eye at point F on the line TR. The latter can be ascertained by an assistant. When you see it the second time at F″, it is really at F′ on the line TL. F and F′, then, are seen in the direction TC. The same is true of every object situated along the lines TR and TL.

When you see F at F″, keep the finger in that position without changing the distant fixation-point. Note that sometimes the finger obstructs the view of the tower; *then you ignore one eye.* Sometimes you see both the tower and the finger, *and the tower through the finger.* Observe the same phenomenon, when the finger is at F′.

In our daily life we sometimes have similar experiences. In a hall we may be able to see the lecturer with the right eye, but to see him with the left eye *the gentleman in front of us ought to be transparent.* As a matter of fact he is sometimes transparent under these circumstances, *provided we pay attention to him.* But usually we are not interested in such "transparent obstructions," and thus

we relegate them where they normally belong: to the waste-heap of neglected sensations (cf. Helmholtz, Phys. Opt., p. 894).

Experiment 99. The following is a variation of the preceding experiment. Hold two uniform paper-tubes (paste-board mailing tubes), about 10 inches long, horizontally and in a parallel position straight before the two eyes, and look through them at a distant object. Provided you really secure the distant fixation-point and thus bring the eyes into a parallel position you will see the two tubes float together and unite into a single tube which is situated straight before the root of the nose, or before the imaginary Cyclopean eye.

Now let an assistant hold his hand at some distance before one of the tubes. It may obstruct the view of the distant object, or you will see both the hand and the distant object in the identical direction, the hand then becoming transparent.

If the assistant now holds his hand alternately before one tube, then before the other, without giving you a clew as to which one he actually covers, you will find it very hard to make this out from your experience.

All these phenomena are in accord with the law of identical visual directions stated above (cf. Sanford, pp. 262 sq.).

2. The Real Significance of the Cyclopean Eye. The most natural question which presents itself at this juncture is this: *Do the facts here experimentally ascertained not bring confusion into our whole perception of space and upset everything that we said before?* If we can see two things as one, and in a direction in which neither of the two is; if an object can be seen as transparent, whilst it is not; and if all this is in accord with a definite law governing binocular vision, what about the value of binocular vision for the immediate perception of space?

The answer is that under normal conditions of attention none of the oddities of the Cyclopean eye can possibly be

a disturbing factor of our immediate perception of space. If in our every-day experience the contingency arises that we see two things as one, they are exactly on a par with the many things seen double. Both go where they normally belong: to the waste-heap of neglected sensations, together with the "transparent obstructions" and things seen in a direction in which they are not. In fact, of all the disturbers of peace we have to keep in check continually, these Cyclopean oddities are the most harmless and least obtrusive. Many of their accomplices on the waste-heap of neglected sensations make a more vigorous attempt to bring chaos into our mental life. But under normal conditions we remain masters of them all through the controlling influence of attention.

To put the matter differently: *For our binocular perception of both distance and direction only those objects come into consideration which at any given time and in any given position of the eyes can be attended to.* Such are normally only the objects in the immediate neighborhood of the fixation-point. *By supposition, moreover, there must be no obstruction in the way of one of the eyes.* For if there is, we actually do not see these objects binocularly and cannot possibly have a binocular perception of either their distances or their directions. Hence only the objects (as for instance T in our diagram), lying at the intersection of any two lines of visual direction (TR and TL) come into consideration when we discuss the problem of the immediate binocular perception of space. *All other objects (such as F and F′), lying on the same lines, are normally not only neglected, but preclude the possibility of our immediate binocular perception of space. Accordingly they are ruled out in our discussion.*

The real significance, then, of the so-called Cyclopean eye can be summed up in the following three propositions: *(1) Though our two eyes can be employed separately, they are normally only two parts of one organ of single vision, which may be appropriately called the Cyclopean eye. (2) The Cyclopean eye is capable of the immediate*

perception of the distance of objects. (3) The direction of those objects, to which we normally pay attention in binocular vision, should not be determined with reference to either the right or the left eye, but to a point midway between the two or the so-called Cyclopean eye. With regard to this third point it is well to add that we follow this rule instinctively. When we say, for instance, that an object seen is straight ahead of us, we do not mean straight ahead of either the right or the left eye, but of a point midway between the two, that is, straight ahead of the so-called Cyclopean eye.

3. **The visual experiences of squinters are pathological deviations from the law of identical visual directions** which we discussed under the heading of the "Cyclopean eye." Adversaries of the nativistic contention have not failed to make use of these deviations to throw doubt on our whole account of visual space-perception. We must, accordingly, consider the facts and the conclusions warranted by them. The accompanying diagram (Fig. 66) will assist the student in following our discussion.

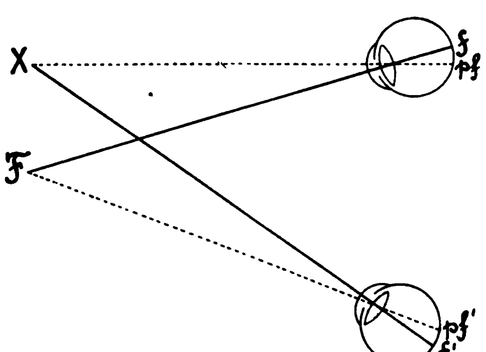


Fig. 66.

Squinters cannot co-ordinate the eye-movements in such a way that the twin images of one and the same object fall on the two *foveae centrales.* When the right eye, for instance, fixates object F, the image of this object falls on

the fovea centralis (f) of the right eye. In the left eye the image of the same object F falls on a point which lies considerably outside the *fovea centralis* and may be called a *"pseudo-fovea centralis"* (pf'). The *true fovea centralis* of the left eye (f'), on the other hand, receives the image of X, while in the right eye the image of the same object X falls on a peripheral point of the retina (pf) and this peripheral point may be called a *"pseudo-fovea"* of the right eye. So much for the eye-movements of squinters and the purely geometrical construction of their retinal images.

As a result of these abnormal conditions the visual experiences of squinters differ considerably from those of normal persons and they differ, moreover, among themselves. On the basis of their visual experiences squinters have been aptly divided by Tschermak into three groups, as we shall explain presently. This classification, then, is a purely psychological one (cf. Beihefte z. Z. f. Angew. Psych., Heft 5, pp. 40 sq.).

For the purposes of our discussion we shall present the first and third groups before the second.

First Group. When the anomaly is congenital or acquired in early childhood, one eye is, as a rule, considerably weaker than the other. The result is that such squinters habitually ignore the weaker eye. Owing to its continual non-use this weaker eye becomes gradually still weaker and at last practically blind. Such squinters constitute the first group in Tschermak's classification. Their visual experiences are entirely a matter of attention and have nothing whatever to do with our account of visual space-perception. Of course, it remains to be explained how such squinters come to perceive the third dimension at all. But this belongs to the chapter on tactual space-perception. For *in this regard* squinters of the first group are on a par, or almost on a par, with the totally blind (cf. Fröbes, *l. c.*, pp. 349-357).

Third Group. When the anomaly is acquired in later life, the visual acuity of the two eyes may be approximately

equal or their difference in this regard is, frequently at least, not so marked as to favor the habitual ignoring of the weaker eye. These conditions given, what are the visual experiences of such squinters? This is again a matter of attention and cannot be expressed by one universally valid formula.

Let us suppose that they attend to the object fixated with the right eye. Then the object fixated with the left eye, will also tend to "attract" their attention. For attention goes naturally with fixation. In terms of our diagram then, the result is that, while they attend to object F, they must struggle to suppress the image of X: *they see double.* These are the experiences of the third group in Tschermak's classification.

Members of this group may also experience a peculiar vacillation of attention, known as "alternating squinting." Now F, now X, succeeds in turn in attracting their attention, the image of X being the disturber in the first case and the image of F, in the second. An unusual condition of attention, substantially identical with that of alternating squinting can be artificially produced in normal persons and is known by the name of *"binocular rivalry."* We shall study it in the chapter on attention and it is to this chapter that the visual experiences of the third group of squinters entirely belong. They have nothing whatever to do with our account of visual space-perception.

Second Group. The same conditions of visual acuity given, there is still another possibility as to the direction of the attention of such squinters. For though attention goes naturally with fixation, *with an effort we may also attend to an object, imaged on a peripheral portion of the retina,* as we explained when discussing peripheral color-vision. In terms of our diagram, we may ignore X, fixated with the left eye, and attend to F, seen peripherally with the same eye. In the case of squinters even less of an effort is required for this unusual mode of attention. For the object F, seen peripherally with the left eye, is at the same time fixated with the right eye. When, therefore, this

unusual mode of attention is resorted to by squinters, ***they combine the visual experiences of non-corresponding points of the two retinas: They see single with the true fovea centralis of the right eye and the pseudo-fovea centralis of the left eye, or vice versa, accordingly as they attend to F or X.*** These are the visual experiences of the second group of squinters. It is their experiences which are held to be irreconcilable with our nativistic account of visual space-perception.

4. The Bearing of the Visual Experiences of the Second Group of Squinters on Our Nativistic Account of Visual Space-Perception. The difficulty which is based on the visual experiences of the second group of squinters may be briefly stated thus: Surely it cannot be said that the *true fovea centralis* of one eye is congenitally co-ordinated with the *pseudo-fovea centralis* of the other eye for the purpose of single vision, but ***this co-ordination is plainly acquired*** by squinters of the second group. ***Why could the same thing not be said of the true foveae centrales of normal persons and their whole system of corresponding points?***

What increases the difficulty considerably is this. By a suitable surgical operation squinters can be cured of their anomaly. Immediately after such an operation squinters of the second group find to their great annoyance that "the operation has done them more harm than good." For now they co-ordinate indeed the eye-movements in the normal manner, but they cannot co-ordinate the visual experiences of the two eyes: they see double. Gradually, however, they simply forget their new trouble and after some time they find to their agreeable surprise that, after all, the operation has been successful. This, of course, means in plain terms: ***They have gradually learned to co-ordinate the visual experiences of those very retinal points which, according to our account, are congenitally co-ordinated for the purpose of single vision*** (cf. Helmholtz, Phys. Opt., pp. 845-847).

The difficulty looks formidable enough and has been often repeated. When we scrutinize the facts a little more closely we find that they warrant these conclusions: 1. *Non-corresponding retinal points may be, and are at times co-ordinated by squinters for the purpose of single vision.* 2. *This abnormal co-ordination depends on the direction of the attention of squinters and is, in this sense, acquired by them.* 3. *When squinters are cured of their physical anomaly, the normal co-ordination of corresponding points depends likewise on their attention and must be acquired by gradually undoing their abnormal habit of attention and acquiring the normal one.* From this it may be further inferred, 4, that *also the co-ordination of corresponding points of normal persons for the purpose of single vision is likewise dependent on attention and, in this sense, must be acquired.*

If this *were* all—or *is* all—that Helmholtz and his followers mean by "empiricism" there is nothing to be said against it, and it implies nothing that is irreconcilable with our nativistic contention. When we call the co-ordination of twin retinal points for the purpose of single vision "congenital," the meaning of this term is not, and cannot be, that single vision with two eyes is independent of attention. No conscious experience of ours is independent of attention. As we have insisted repeatedly, *attention dominates our whole conscious life, and single vision with two eyes is no exception to this rule.*

But the "empiricism" which we rejected implies much more than is expressed by the above four conclusions. What we rejected is the "local-sign-theory." Our nativistic doctrine, on the other hand, implies much more than the fact of single vision with corresponding points of the two retinas. Our doctrine, so far as it touches binocular vision, is mainly concerned with *the slight lateral disparity of the two retinal images and with the manner in which this slight lateral disparity forms the basis for the binocular perception of distance.*

By means of a purely geometrical construction it is. of

course, possible to make out that squinters of the second group acquire also a new system of laterally disparate points, that is, a system of retinal points whose lateral disparity is determined with reference to *the true fovea centralis of one eye* and *the pseudo-fovea centralis of the other eye*. But such a purely geometrical construction is—of itself—no proof against our nativistic doctrine. What is decisive are the visual experiences of squinters.

To disprove our nativistic contention, it would be necessary to establish that *such an abnormal system of laterally disparate points becomes for squinters the basis of the binocular perception of distance.* In more precise terms, it would be necessary to establish this proposition: *Whenever the abnormal disparity of retinal images is slight, objects, thus imaged (and attended to), are not only seen single but are localised before or behind the abnormal common-fixation-point, according as the disparity is crossed or uncrossed.* In the interest of the local-sign-theory it would be necessary to prove, in addition, that *this localisation of objects in the third dimension is acquired on the basis of the kinaesthetic sensations arising from the eye-movements of squinters.* **Of all this there is not even a shadow of evidence in the experiences of squinters** (cf. Fröbes, *l. c.*, pp. 267-269; 290-302; 325-332).

CHAPTER XIII

ATTENTION

1. The Foreground and Background of Our Sensory Experience. Our account of sensation would be very incomplete, if we were simply to say that an object by its activity causes a definite change in a sense-organ and that the latter then responds to this change by a conscious sensation. For there are a great many objects which act simultaneously on one and the same sense-organ and all the other sense-organs are acted on at the same time by a host of other objects. If the great variety of changes thus brought about simultaneously in the various sense-organs were answered each by a conscious sensation, chaos would be the inevitable result. But, as a matter of fact, our normal sensory experience is far from being a chaos. Only a limited number of objects succeed at any given time in gaining an entrance into our conscious life. Their rivals are for the time being more or less rigidly excluded or, maybe, put on the waiting list. Now the object, or the definite group of objects, which at any given time successfully enters into our conscious life is "attended to," the others are "not attended to," they are ignored.

There are, then,—to use a figure of speech—always a foreground and a background in our normal sensory experience, the foreground being occupied by the favored few, the background by those rejected or on the waiting list. For those rejected remain there and hammer away as vigorously as before at the gates of our senses and—what is more—they are actually heard, seen, and felt, though they are not attended to. As you read this page, the ticking of the clock in the room is not in the focus of attention. The rumble of the street-cars and the rest of the city hubbub are not even on the waiting list. But if all these noises stopped suddenly, you would find out very soon that

something is lacking in your experience. It is the background of rejected sensations, which belong as much to your normal experience as the foreground. Moreover the next moment may bring a reversal of things: the present occupant of the foreground may change places with any one of those in the background.

2. The Foreground and Background of Thought. A similar condition prevails when we are thinking of some object not present to our senses or incapable of being thus presented, as when we are thinking of some scientific or philosophic problem. Then not only most objects of sense—possibly all of them—recede to the background, but with them also many objects of thought and fancy. For it is a well-known fact that none of us can think of any subject for a length of time without distractions. This means that the machinery of association introduces into our mind many an irrelevant thought and fancy which we are struggling to keep in the background, but which succeeds nevertheless—ever and anon—in actually occupying the foreground.

It would be far from an accurate description of our intellectual life, as it actually occurs, if we were simply to say that by some process of association the idea of a definite object arises in our mind, and this in turn by force of association calls up the idea of another object, and thus, as one brain-cell awakens another in regular succession, our ideas pass in Indian file before our mind. There are a great many things to be said against such a description of our rational life. Here it may suffice to point out that all objects of thought and fancy are interconnected in a thousand different ways and have been thus associated in our past experience. Hence it would be very surprising indeed, if the thought of a definite object called up in our mind only that associate which fits here and now into the rational sequence of thought. If associations are effective, they must be effective in various directions. If, however,

all of them were *equally* effective, then indeed no rational sequence of thought would be possible.

The finished product of our mental work as presented, for instance, in an orderly essay, is one thing, and the actual work-shop conditions under which it arose are quite another. An orderly essay presents only the foreground of thought, and that considerably idealized. For many irrelevant intermezzos, breaking up the rational sequence of thought, are carefully eliminated. But there was also a background, and most writers would probably be mortified if it too were put on paper. And justly so. For thus equal emphasis would be given to the irrelevant thoughts and fancies and to the orderly sequence of thoughts. But this was not so. The irrelevant thoughts, though present, were not attended to, except during the pardonable intermezzos. The objects of the writer's attention were those presented in the orderly essay. He "minded" the latter; he "did not mind" the former.

3. The Narrowness of Consciousness. These familiar facts are not explained but only called by another name, when we refer to them as "the narrowness of consciousness." Why is our consciousness so narrow? Why are not the gates of our senses equally open to all comers, and why are not all processes of association equally effective?

Is it a question of strength among the rival claimants of attention, so that those who hammer hardest force their way into our conscious experience? This is indeed at times the case, but it is far from being universally true. We may pick out, for instance, a faint noise, the ticking of a watch, as the object of attention.

Or is it a question of voluntary choice among objects, so that we ourselves open the gates of our senses for one object and lock them against all others, and voluntarily direct the processes of thought into definite channels? This again is true at times, but not universally. For frequently we are simply overpowered by an object which "attracts" our attention, at least for the time being. In

other words we must recognize the fact that there are two kinds of attention, voluntary and involuntary.

Nor can it be said that those objects successfully enter into our conscious life which are "interesting," that is, appealing to our natural or acquired tendencies. For a repulsive object may force its way into our mind, although it cannot be brought or kept there voluntarily, unless it derive some interest from some other object, inherently interesting. In other words, interest is indeed an important factor of attention, but attention itself is not interest.

Nor again can it be said that those objects occupy the foreground of our consciousness which are presented most clearly to the senses or the intellect. For we may select a vague and undefined object for attention. Clearness is rather an effect of attention, not an essential feature of attention itself, unless indeed by clearness of an object nothing else is meant than that here and now it occupies the foreground of consciousness. For thereby also a vague object acquires prominence over the neglected background.

Nor, finally, should attention be confounded with the characteristic bodily attitudes, which we assume—for the most part instinctively—when we attend to some object of sense or thought. These attitudes are rather accompaniments of attention: adjustments of the sense-organs and of the whole body for the favorable reception of helpful stimuli and the exclusion of distracting ones. As a result they become signs for us by which we judge whether others are attentive or not. In Scholastic terminology these bodily attitudes were aptly designated "external attention" in opposition to attention proper or "internal attention." By a voluntary effort, moreover, we can also attend to an object of sense for which the sense-organ is not adjusted. Such was for instance the case in our experiments on double images and on peripheral color-vision.

4. **What is Attention?** Accordingly neither voluntary choice nor interest nor bodily attitudes on our part, nor force nor clearness on the part of the object, are essential

features of attention. What, then, is the essential feature present in all states of attention? What is attention?

We cannot define attention in any other way than by the use of some metaphor. Thus we say that we "direct" or "concentrate" or "focus" our mind on one object and not on others. Or we say that our mind is "occupied by," or "absorbed in," one object in preference to or to the entire exclusion of others. Or again we say that an object moves to the "foreground of consciousness," whilst others stay in its "background." Now when we come to analyse these metaphors, and realize that they must fit both voluntary and involuntary attention, attention both to an "interesting" and to a "repulsive" object, to a "clear" as well as to a "vague and undefined" object, we find that we are only using circumlocutions for stating again the marvellous fact of the "narrowness of consciousness." In other words we simply restate the fact that out of a multitude of stimuli simultaneously bombarding our senses, and out of several processes of association going on simultaneously, only one or a limited number is for the time being successful in gaining an entrance into our conscious life, and the others—well, they are not successful here and now. And this was the fact with which we started out.

In other words attention is a primitive and irreducible fact of our experience which is none the less mysterious because it is so familiar to us. We do not mean to clarify this mystery, but simply to embody all the above facts in a short-hand phrase when we "define" attention as *the voluntary or involuntary direction of our mind towards one object of sense or thought, or a definite group of such objects, to the more or less complete exclusion of all others.*

5. Subconscious Sensations, Fancies, and Thoughts. Familiar phenomena, no matter how mysterious and wonderful they may be, come to us as a matter of course. But when the same phenomena are presented to us under unusual conditions, we are puzzled and liable to accept the most grotesque interpretations put upon them. So it is in

the realm of physical phenomena, and so it is also in the realm of psychology.

The phenomena of hypnotism, table-turning, Ouija-board writing and all other forms of automatic writing are so weird and extraordinary, that by some they are thought to be of their very nature outside the realm of psychological inquiry, while others see in them evidences of a most outlandish metaphysical theory in modern psychology, namely, that of the "double Ego" or "double personality," the one conscious or normal, the other subconscious or abnormal. The truth here, as elsewhere, lies in the middle.

It is not our purpose at present to inquire into the real nature of these weird phenomena. We can do so successfully only after we have studied a number of other psychological data, which enter likewise into their explanation, especially the nature and origin of the various kinds of external action. Here we wish only to prepare for this future discussion by answering two questions, which are fundamental in this regard, namely: (1) Is there such a thing as a subconscious sensation or thought? And if so, (2) are we ever guided in our outward actions by subconscious cognitions?

The reader who has carefully followed our discussion in the previous paragraphs cannot be in doubt as to what the answer to the first question should be. Of course, there are subconscious sensations and thoughts, and not only by way of exception, but we are never without them. There are always a foreground and a background in our conscious life. Subconscious sensations and thoughts are but other names for this background.

There are certain curious facts of "immediate memory" which cannot be explained except in the hypothesis of subconscious cognitions. *We sometimes become conscious of an experience only when it is recalled shortly after it has occurred.* Thus, for instance, when walking on the street, you may pass somebody without recognizing or even noticing him. Of course, if your eyes were not closed, he made an impression upon them. But absorbed as you are

in your own thoughts, you have seen him as if you saw him not. When, however, he is two or three steps behind you, his features and manner of walking arise clearly in your mind. You recognize him as Mr. So-and-so. Promptly you turn around to address him. Or you may have an appointment for 4:00 P. M. Busy as you are with your work you entirely fail to notice the house clock striking that hour. Right after, however, you become aware of the fact. So distinctly are the past sounds recalled that you can count them with precision. How could you recall sounds which you never "heard"? But you have heard them as if you heard them not. Your experience becomes conscious only when it is recalled (cf. Ebbinghaus, Gr. d. Psych., pp. 48 sqq.; James, Pr. of Psych., I, p. 646).

6. Subconscious Activities. As to the second question a little reflection will show that this too must be answered in the affirmative. You may be engaged in an animated discussion with your friend whilst walking up and down with him in the garden, avoiding obstacles as you go along, and turning at the right time. In addition you may be playing with the button of your coat, slipping it alternately through its proper hole and back again, incidentally interrupting this operation by driving away a fly that insists on landing on your nose—and all this with your mind most intently focussed on the subject of your discussion.

Now you cannot avoid obstacles in walking and turn in the right place without being guided in these operations by some cognition of the obstacles and the place for turning. Yet none of these cognitions is here and now in the focus of attention. In walking, too, you feel the ground at every step. The contractions of your muscles cause likewise a number of sensations. You feel also the button and your coat. If your hands and feet became suddenly deprived of sensation, you could not perform any of these operations. The plain fact is that the various sensations mentioned are indispensable links in the chains of move-

ments which make up the simple acts of walking and buttoning the coat.

What adds to the marvel of your performance is that the acts of walking and buttoning your coat are—physiologically considered—far from being as simple as we are liable to think. They require a great many co-ordinated movements, too complex to be explained here. And when these operations were performed for the first time in your life, they required a good deal of concentrated attention. There were, moreover, many attendants there to see that these feats were done right. Now as you are discussing a scientific problem with your friend, these operations and the various sensations with which they are linked, never come to the foreground of your attention. *You are guided in these operations by subconscious sensations* (cf. Ebbinghaus, l. c.).

Subconscious fancies and thoughts are no less effective in guiding outward actions. You may be absorbed in reading an interesting novel in the library and be not even aware that you are annoying your friend, who likewise tries to read. Unwittingly you drum with your fingers in time with a familiar tune that is running through your head. If you are a piano-player, you may under the same conditions, and just as unwittingly, execute the complicated series of movements involved in playing on an imaginary keyboard the familiar piece of music that you hear in the background of your imagination. Such and a thousand other similar occurrences of our daily life leave no room for doubting that subconscious cognitions of all kinds may, and frequently do, guide us in the performance of outward actions, and sometimes of highly complicated ones.

7. **Expectant Attention.** We said that certain objects "are on the waiting list." This is more than a mere figure of speech. For our expectations, previous knowledge of all kinds, and acquired mental tendencies are most important factors in determining whether a certain object will pass unnoticed or actually reach the focus of attention. Hence we speak of expectant attention. Its influence is to

a great extent a matter of daily observation. A popular adage has it that *the wish is the father of the thought.* This is true not only in the opprobrious sense in which the adage is mostly used, but also in a very good one. As the matter is of great theoretic and practical significance we shall study experimentally the effects of expectant attention.

Experiment 100. On the harmonium hold down the key which corresponds to c of the small octave (1 in Fig. 67). Be sure to use only one stop, namely an 8 foot stop, so that only one tongue is vibrating when you press the key. The tone produced by the vibrating tongue seems simple and unitary. As a matter of fact, however, it is a clang or compound tone, consisting of a number of partial tones, of which the one indicated by the musical notation is only the principal or fundamental one. Not only the tongue as a whole, but also its various (aliquot) parts are vibrating, the ratios of these various vibrations being: 1 : 2 : 3 : 4 : 5 : 6 : 7 : 8, and so on indefinitely. Quite a number of these indefinitely many vibrations are, as a matter of fact, physically eliminated. This is a matter of physics, and need not detain us here. Others are at least very weak. All of them, except the principal or fundamental one, are comparatively weak, and thus not separately heard, unless we direct our attention to any one of them in particular or to a definite group of them.

Now suppose you get the instruction—and this is the instruction in the present experiment—to pay attention to the third partial of the compound tone you hear, that is, to bring this partial from the background into the foreground of attention. How are you ever going to carry out this instruction? It is like telling you to look for Mr. Jones, when you do not know how Mr. Jones looks nor where he might possibly be. You would not know that you had found him, even if you came upon him accidentally.

If you are to be successful in your search you must have a premonitory image of the object which you are looking for. In the present experiment you must know beforehand

how the said third partial sounds. It sounds like the tone marked 3 in the accompanying figure.

You insist that you are not a musician and are, therefore, incapable of carrying out the present experiment. The fact is, you need not be a musician to carry out the experiment, nor does it denote any hidden musical talent in you, if you

Fig. 67.

are remarkably successful. It is exclusively a matter of attention. The only thing in which a good musician is ahead of you—for the purposes of the present experiment—is this. Once the fundamental tone is given, the musical notation of its third partial suffices for him to call up the premonitory image of the sound he expects to single out by attention. If you are not a musician, then, have a musician friend play for you on the harmonium first the fundamental (1) and then its third partial (3). Now you know what the latter sounds like.

Then proceed to the experiment proper. Press down the key of the fundamental tone again, and at the same time sound, as softly as possible, the third partial on the harmonium. Discontinuing then the sounding of the partial, listen attentively whether there is not a similar faint sound to be heard, when you press the key for the fundamental alone. With repeated trials you will be successful. And when you are successful, you are not imagining a sound which does not exist in nature, but your imagination and expectant attention have helped you to single out an extremely faint sound, which without expectant attention would surely have passed unnoticed (cf. Helmholtz, Sensations of Tone, tr. by Ellis, pp. 49 sq.).

Proceed similarly in singling out successively partials 5, 6, and 7.

It may be well to add that by means of a properly adjusted Helmholtz resonator any partial tone can be detected with ease. But this mode of procedure only proves the physical existence of the partial vibration for which the resonator is adjusted. For when you hold the resonator to the ear, you really do not hear the faint partial of the vibrating tongue, but the comparatively strong sound, produced by resonance in the air column of the resonator.

Experiment 101. Strike on the harmonium the chord indicated below (2 in Fig. 68), using an 8 foot stop for the experiment. Though four notes are sounding simultaneously, they come to most people as a unit whose component parts are not separately attended to. But we can attend to any one of them in particular, and that with comparative ease, provided we have a premonitory image of the sound which we wish to single out. To secure this image, play one of the tones of the chord separately, say c′. Knowing now what you expect to hear, strike the chord again and hold it. Direct your attention to the tone whose

1. The melody you expect to hear. 2. The Chord to be analysed.

Fig. 68.

memory-image you have in mind. *It will now sound louder* than the other tones of the chord, or more correctly, *it will now be in the foreground of attention,* whilst the other tones recede to the background.

In a similar manner we can single out successively every tone of the chord, so that we hear a sort of simple melody. To do this, play first the melody you expect to hear (1) but play it slowly; then strike the chord and hold it (2). Now pay attention successively to the notes

as they follow one another in your memory-image of the melody. By means of expectant attention you thus single out successively the component parts of a chord, which without this expectant attention would have come to you as a unit (cf. Titchener, Exp. Psych., I, p. 111, and Helmholtz, l. c. pp. 59 sq.).

8. "Habitual Setting" of Attention or "Einstellung". Very much akin to expectant attention is what German psychologists call "Einstellung." A typical example will show what is meant by this term.

In the part of every orchestra-performer the following musical notation (1 in Fig. 69) occurs time and again. Of course it depends on the clef and the signature (2 and 3 in Fig. 69), placed at the beginning of the musical staff,

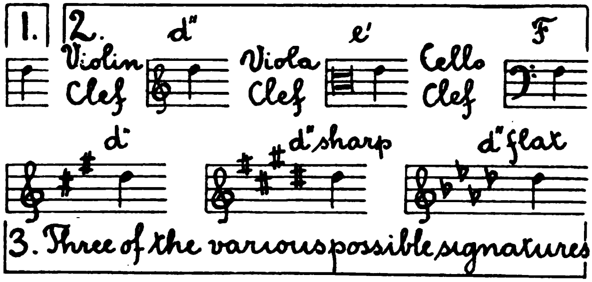


Fig. 69.

which note is meant in the part of each performer. The result is that the same musical notation means one note for the violinist, another for the viola-player, again another for the cellist, and so forth. Even for the same performer it means one note in this piece of music, and another in another piece of music. Before starting to play, each performer notes his clef and the particular signature of this piece of music, and thus *sets his attention in a definite direction.* The result is that out of various possible interpretations of the above musical notation only that one comes to his mind, for which his attention is set and that without ever afterwards referring explicitly to the clef and signature which determine its meaning. As will be seen

from this example, "Einstellung" is really nothing else than "habitual expectation", or an "habitual setting of attention."

The same factor is present in the conscious life of every individual. The mental habits of men differ as widely as their occupations, and these habits limit each one's horizon and determine his point of view. The chemist lives in a world of his own, the physicist in another, the biologist, the mathematician, the farmer, the tailor, and so forth, each again in another. In other words, each one has acquired a definite turn of mind: his attention is set habitually in a definite direction. Hence it is that one and the same object of sense will be noticed by one and not by another, arouse a definite thought in one and a widely different one in another.

9. Sense-Illusions and Errors of Judgment Due to Expectant Attention. So strong are our expectations in determining the direction of our attention, that many sense-illusions and errors of judgment have their origin here. A typical example of a sense-illusion of this kind is the following.

Experiment 102. Fill a small box with shot. Then take a larger box of the same shape and material, and place enough shot in it that the two boxes are of exactly the same weight. This determination should be made by means of an accurate balance. Now ask some one, who does not know how these boxes were prepared, to lift one after the other and to tell which of the two seems the heavier. It will invariably be found that the smaller box is judged to be decidedly the heavier one. In lifting the small box we experience a certain effort. Seeing the other box of the same material and shape, but larger than the first, we expect to experience more of an effort in trying to raise it. The actual effort falls considerably below our expectation, and as a result we judge the larger box to be the lighter one.

The result will in most cases be the same, if the small

box is actually somewhat lighter than the larger one and even after the subject of the experiment has found out how the boxes were prepared; so strong is the influence of suggestion.

That it is really the said expectation which is responsible for the illusion can be tested in the following manner. Prepare two additional boxes, larger than the first two, and of equal weight, shape, and size. Enclose the small box in one of the latter, the larger one in the other. Then no expectation influences us in testing the weights and the illusion is gone. There may indeed be errors, but just as well in favor of the one as the other box (cf. Witmer, Analyt. Psych., p. 20).

Similar sense-illusions of all kinds are due to expectant attention. Children going out in the dark and with their minds filled with ghost-stories, will actually "see" what they are only too afraid to see: a ghost. Anything, a white sheet moving in the wind, a shrub, or what not, will be interpreted in accordance with their expectant attention.

Even grown people, in fact a whole multitude, may thus become victims of their expectant attention. The following occurrence quoted by W. C. Carpenter in his "Mental Physiology" is to the point.

"During the conflagration at the Crystal Palace in the winter of 1866-67, when the animals were destroyed by the fire, it was supposed that the chimpanzee had succeeded in escaping from the cage. Attracted to the roof, with this expectation in full force, men saw the unhappy animal holding on to it, and writhing in agony to get astride one of the iron ribs. It need not be said that its struggles were watched by those below with breathless suspense, and, as the newspapers informed us, 'with sickening dread'. But there was no animal whatever there; and all this feeling was thrown away upon a tattered piece of blind, so torn as to resemble, to the eye of fancy, the body, arms and legs of an ape!" (l. c., p. 209).

Errors also of the gravest sort may be due to expectant attention, especially if they become habitual and take com-

plete possession of the mind. We all know what bias can do. It blinds its victims to everything that does not agree with their bias, and makes them actually see things which exist only in their prepossessed minds. This is true not only in the realm of religion and politics, but also in the domain of experimental science. The same facts may be investigated by two observers, the one with unwarranted assumptions in his mind, the other without such assumptions and ready to let the facts speak for themselves. The two will differ not only in the interpretation of what they have observed, but in all probability even in the phenomenal description of the facts themselves. Take, for instance, the assumption of evolution. We do not speak here of that form of the theory of evolution, which is kept within the limits of a strictly scientific hypothesis, but of that sweeping metaphysical dogma of evolution *which must be true, whatever else may be true.* Investigators who approach psychological facts in this frame of mind, will actually see evidences of the chimpanzee where there is only a tattered blind.

10. The Span of Attention. To how many objects of sense or thought can we attend simultaneously? The story is told of Julius Caesar that he actually dictated four letters, while writing a fifth. Similarly expert chess-players are reported to have played simultaneously five, ten, or even more games blindfolded. But here the word "simultaneously" is used in a rather loose sense. What really occurs in these and similar cases is a rapid "oscillation of attention." In other words, there are persons who are remarkable for their ability to turn rapidly from one subject to another. Hence their performances prove rather an extraordinary memory and an unusual flexibility of controlled attention, but do not throw any light on our present question.

By way of digression it may be stated here that diametrically opposed to this unusual flexibility of controlled attention is that absolute rigidity of uncontrolled attention

which occurs as a pathological condition, namely that of "fixed ideas." The mean beween these two extremes is the normal condition which should be aimed at by all. We should never allow ourselves to become so engrossed by any one thing—be it study or play or anything else—that we cannot turn our mind to something else when duty calls.

To return, then, to our original question. It really amounts to this: How large can the "group of objects" be of which we spoke in the definition of attention? How many units may such a group contain, and yet allow us to give *equal* attention to all? Unless this equality in the distribution of attention is included in the question, we have answered it already, when speaking of the foreground and background of attention. For among the things in this background there may be some that are rather near to the foreground, that is, which are somewhat less attended to than the object in the foreground.

Several experimental arrangements—some of them rather elaborate—have been devised to answer the question stated. But the interpretation of some of the experimental data obtained has been justly criticised (cf. Ebbinghaus, Gr. d. Psych., pp. 591 sqq.). We shall not enter into any details but rest satisfied with recording the brief summary of results, as given by Ebbinghaus.

In the case of very simple mental tasks (such as the perception of simple objects of sense, or the making of easy and obvious considerations, or the execution of simple routine movements) attention may be easily divided between two, possibly three, independent things.

The more complex, however, a mental task is, that is, the greater the number of parts which it involves, the more it becomes impossible to do justice at the same time to another task. Though attention may then be equally distributed among the different parts of such a complex task, these parts are not focussed as independent units but precisely as interconnected parts of one and the same task.

All this, moreover, cannot be done with equal success by every individual nor by the same individual at all times.

In other words, there are not only individual differences in this regard but success depends also on the actual condition of the subject at the time of the experiment, particularly as to whether he is fatigued or fresh (cf. Ebbinghaus, l. c., p. 594).

The practical conclusions from these experiments are: (1) In the case of trifling tasks you gain time (or, at least, you lose less), if you do two or three of them simultaneously. Thus, for instance, if you must listen to a twice-told tale, and must read the gossip-column of the newspaper for the third time, you may profitably combine the two tasks. (2) If several serious tasks demand your "immediate" attention, the quickest way of doing justice to them all is to do strictly one at a time and each in its proper order. You gain time in this way even for your sports.

6. Fluctuations of Voluntary Attention. The most important form of attention, that on which all success in the intellectual and moral advancement of every individual depends, is voluntary attention. If a student can be prevailed upon to concentrate his mind on the subject to be mastered; if one that tries to overcome an evil habit, in every temptation deliberately fixes his mind on the motives which prompted his resolve; if in any enterprise whatever we carry out consistently the golden maxim "*Age quod agis,*" "Do what you do," that is, do with undivided attention, whatever you do: then success will take care of itself. But the difficulty is in carrying out these precepts. Voluntary attention is difficult, and that for two reasons.

In the first place there are so many claimants to attention, and many of them appeal rather strongly to our natural tendencies. Unless we make an effort and renew this effort frequently, we shall find ourselves distracted, and following the line of least resistance. We are only too keenly aware of these fluctuations of voluntary attention from our everyday experience. Unless we are on our guard, we shall find ourselves wool-gathering and dilly-dallying, before we

make even the first effort in the right direction. "I know a person, (says James) who will poke the fire, set chairs straight, pick dust-specks from the floor, arrange his table, snatch up the newspaper, take down any book which catches his eye, trim his nails, waste the morning *anyhow,* in short, and all without premeditation,—simply because the only thing he *ought* to attend to is the preparation of a noonday lesson in formal logic which he detests. Anything but *that!*" Ebbinghaus, quoting this passage, wittily adds that in all probability the reader knows such a person too.

In the second place, though voluntary attention can be "sustained," even for hours together, if its object arouse our interest, it is strictly speaking not true that we in such a case pay uninterrupted attention to the same identical and unchanging object. We simply cannot do this except for very brief periods at a time. The most deliberate effort will not carry us further. The object will in spite of ourselves periodically drop out of our mind.

Common experience would seem to be against us, for we know that by an effort we are capable of "sustained attention to one and the same object." But there is an ambiguity here in using the term "object." A topic is an object, and its various phases or aspects are objects. If we get interested in anything, it will grow and develop in our mind, and branch out in various directions. In other words, its various phases or aspects will be presented successively to our mind, and thus it will hold our attention. When this takes place, a great multitude of thoughts pass through our mind, each with its own object. But these objects are all phases of one and the same topic. Though thus the direction of our attention is continually changing, we call it "sustained" attention, as long as we revolve the same topic in our mind. As soon as the interest in the topic flags, it ceases to develop and drops out of our mind: we pass to something irrelevant and are "distracted."

From this it will be seen what an important role interest plays in attention. It makes voluntary attention easier and

sustained attention possible. Voluntary attention, sustained by interest, gradually shades off into involuntary attention. Once we have launched ourselves on a definite topic with a deliberate effort, we are carried along by the stream of thought it provokes, and this stream of thought can be called voluntary only because it depends on the deliberate effort by which we launched ourselves on this stream. Either the object must be thought-provoking or we must provoke the thought, and it is the continual alternations of these two processes that constitute the fluctuations of voluntary attention (cf. James, Psych., pp. 224 sqq.).

All this is but an analysis of our common experience in this regard. We may study the matter also experimentally. The following experiments will bear out what we have said, namely, that voluntary attention to one and the same unchanging object cannot be sustained except for very brief periods at a time.

Experiment 103. The accompanying figure (Fig. 70) is an equivocal one, admitting of several spatial interpretations. It is not drawn in true perspective, nor is the shading what it ought to be if the figure were meant to

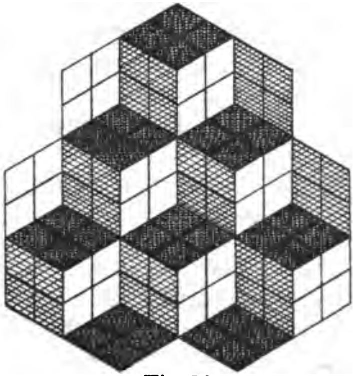


Fig. 70.

represent solid objects in relief. There are, however, strong suggestions, both as to perspective and shading, of a number of cubical blocks.

If we go simply by the data of our immediate experience, prescinding entirely from the criteria of relief which previous experience has furnished us, we can interpret the figure to be just what it is: a geometrical pattern, consisting of 96 diamond-shaped quadrangles, all of the same size, 32 white, 32 light grey, 32 dark grey, juxtaposed in a definite order on a flat surface. *Looking at the figure,* can you really prescind from the criteria of relief, and thus interpret the figure as a flat geometrical pattern? If so, how long? It requires an heroic effort to do this even for a brief period of time. The immediate data of your present experience have been associated a thousand times in the past with the third dimension, with relief. It is extremely difficult to prevent these habitual associates from entering your mind together with the immediate data of your experience.

The experiment is very instructive. We experience here just what happens, whenever we try to direct our mind to any definite object and to keep the latter uninterruptedly in the focus of attention. If the object has had associates in the past,—presto! they are called up too. If they are relevant, belonging to the same topic,—well, we are not yet distracted. The object only grows and develops in our mind. If, however, the associates are irrelevant, our mind begins to wander after the first effort. Happily the associations which most objects have formed in our past experience are not so deeply rooted as those which we have to contend with in the present experiment. We rarely meet such irrepressible associates.

Experiment 104. Yielding to the suggestion of relief, you will interpret the figure as a representation of a number of cubical blocks. Count the blocks! Are there six or seven? As the figure is not drawn in true relief, the suggestion it contains of six blocks is just as strong as that of seven. Which of these two interpretations will come to you first, no one can foretell, at least when you see the figure for the first time and without any definite expecta-

tion. But once you have a definite interpretation in your mind, try to keep it voluntarily in your mind as long as possible! How long do you succeed? Possibly even before you have finished counting the blocks, as directed, the aspect of the figure is changed entirely. Instead of six blocks you now see seven, or vice versa. Now try to hold this second interpretation steadily before your mind! Presto, the figure turns over again.

You can study here experimentally, how far an effort of your will can carry you in contending with rival associations. In studying your lesson in logic, or physics, or biology you will come upon many objects which have been associated in the past with other objects. If you are intensely interested in your lesson, the struggle will not be so hard, especially as many of these past associations help to develop the topic which you revolve now in your mind. But you will not succeed in holding an unchanging object in your mind except for very brief periods at a time.

The obvious practical conclusion from these experiments is: Get interested in whatever you study, and try to connect whatever new things you learn with the things you know already, not only with those you have learned in the classroom but with anything and everything that has interested you before. The contagion of interest will spread from one object to another, and thus you make allies of those very associates which might prove your greatest adversaries (cf. James, Talks to Teachers, pp. 91 sqq.).

Experiment 105. Materials: A stereoscope, prepared in the manner explained in the last chapter.

View the following "stereogram" by means of the stereoscope. Of course, you cannot possibly combine the right-hand view with the left-hand one, nor are you to attempt this. The instruction in this experiment is, simply to ignore one eye, first the right eye, then the left one. This you can do with more or less success, provided you go at the task with a deliberate effort. The sincerity of this effort, however, will be put to a most severe test.

In the beginning the two prints will become hopelessly mixed. After that one of them will periodically replace the other. This is known as "binocular rivalry." If you want to be successful in reading the text from the beginning to the end with as few interruptions as possible, you must be methodical in the experiment. Thus, for instance, you may profitably read the whole text, before using the stereoscope. Then your expectant attention will help you greatly in carrying out your resolve. Other means to success are indicated in the text of the "stereogram" itself. The latter is really the comment of Helmholtz on the next experiment (Experiment 106).

"I find that I am able to attend voluntarily, now to one and now to the other system of lines; and that then this system remains visible alone for a certain time, whilst the other completely vanishes. This happens, for example, whenever I try to count the lines first of one and then of the other system. . . . . But it is extremely hard to chain the attention down to one of the systems for long, unless we associate with our looking some distinct purpose which keeps the activity of the attention perpetually renewed. Such a one is counting the lines, comparing their intervals, or the like. An equilibrium of the attention, persistent for any length of time, is under no circumstances attainable. The natural tendency of attention when left to itself is to wander to ever new things; and so soon as the interest of its object is over, so soon as nothing new is to be noticed there, it passes, in spite of our will, to something else. *If we wish to keep it upon one and the same object, we must seek constantly to find out something new about the latter,* especially if other impressions attract us away." (James, Psych. p. 226).

Experiment 106. Combine binocularly the two systems of lines in the following "stereogram" (Fig. 71). In doing so profit by the comment of Helmholtz on this experiment.

In the last two experiments you can study experimentally

what you must do, if you are in earnest about studying your lessons under powerful external distractions. You can find out, too, how to go about thinking or meditating on a definite topic so as to avoid distractions. If you take no precautions, but simply present the object of thought to your mind, the object will go out in a short time. But

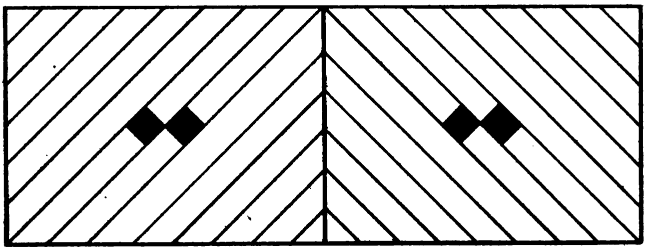


Fig. 71.—(From Helmholtz.)

if you revolve it in your mind, ask different questions about it (such as "who, what, where, with what aids, why, how, when?") you will succeed, that is, more or less. There is no other road to success.

Experiment 107. In a quiet room have an assistant hold a watch at such a distance from your ear that you can just hear its ticking. When this distance has been ascertained, close the eyes so as to exclude all disturbing visual stimuli, and being seated comfortably, listen as attentively as possible to the ticking of the watch. The faint sound you hear is near the threshold of audibility and thus very favorable for the observation of fluctuations of attention. It would be best to employ a continuous sound of medium pitch and just as soft as the ticking of the watch. But this is difficult. Though the ticking of the watch is, strictly speaking, not an unchanging object of attention, the succession of faint sounds, of which it consists, is monotonous and thus equivalently an unchanging object. It is easy, moreover, to prescind from all associations which the ticking might arouse; such associations, if there be any, are not liable to be very obtrusive, so

that you can direct your attention exclusively to what is immediately given in your sensory experience.

These conditions secured, we find, that the ticking of the watch will periodically grow still fainter and drop entirely out of our mind. There will be fluctuations of voluntary attention which can be recorded in the form of a curve.

To make an accurate record of this kind, rather elaborate apparatus is required. But for the purposes of our present experiment there is no need of strict accuracy. For the main point of interest is not to know in terms of seconds and fractions of a second, how long the various phases of our fluctuating attention last. We are rather interested in ascertaining the main fact itself that such fluctuations occur under the conditions described, normally even several times during the space of one minute. Proceed as follows.

When you actually hear the ticking clearly, raise your hand and keep it raised, as long as you hear the ticking. When it vanishes out of your mind, lower the hand. An assistant should see to it that each experiment begins and ends, when the second-hand of the watch is at 60, so that each experiment lasts one minute. Before the experiment proper he should draw on a piece of paper a straight line and divide the latter into six equal parts, which he marks 0, 10, 20, 30, 40, 50, 60. These figures stand for seconds. During the experiment proper he simply follows the hand-movements of the subject and thus makes a curve, indicating the fluctuations of voluntary attention. If none occur within a minute, it shows that the watch is held too near (cf. Seashore, pp. 158 sq.).

Similar experiments have been devised for ascertaining and recording the fluctuations of voluntary attention, when it is directed to *visual* and *tactual* stimuli. The results are, in general, the same as described above (cf. Titchener, Exp.. Psych. I, pp. 111 sqq.).

It may be well to add that the results of the latter ex-

periments are complicated by the fact that the organs of sight and touch readily become fatigued. This shows itself, for instance, in troublesome visual after-images and in a general blur and confusion, resulting from so steady and unchanged an application of the eyes. Hence we really do not know any longer whether we are studying the effects of sensory adaptation or the problem proper, namely, how far a voluntary effort will carry us (cf. E. A. Pace, in Phil. Studien, Vol. 20, pp. 232 sqq.).

CHAPTER XIV

SENSE-PERCEPTION

1. In our adult experience we have rarely—if ever—mere sensations in the technical sense of the term.

What the conscious experience of a new-born babe may be when its sense-organs are bombarded for the first time by sensory stimuli, we cannot tell except by inference and after a good deal of abstraction. It must be a confused medley of sensations pure and simple, a sort of general "Hello!" with which the young philosopher-to-be meets and greets this sublunary world of ours. We say "sensations pure and simple," that is, *sensations in the technical sense,* namely, *conscious experiences which are but the immediate results of actual stimuli affecting the sense-organs, without any suggestions or associations with past experiences.* Accordingly the smile of the mother, her endearing words and caresses, do not mean "mother" or a "mother's love" to the baby. They are but sensory stimuli, on a par with any other stimuli that may affect its organs of sight, hearing, and touch. And they are responded to only by the immediate results of these stimuli: visual, auditory, and tactual experiences of the objects present, without any suggestions or associations with past experiences. For the new-born babe has had no conscious past experiences, the incoming sensations being the first inscriptions recorded on the "tabula rasa" of the babe's mind.

Now such a condition can never occur in our normal adult experience. For our minds are stored with records of the past. Every incoming sensation is an accretion to this store of our mental possessions, and, what is more, it comes with suggestions of some portion or other of our past experiences. The result is that no impression made on our sense-organs evokes merely its immediate conscious

response—a sensation pure and simple—it awakens and revives also experiences which in the past have been associated with such a sensation. So readily, in fact, do associations cluster around, and combine with, our actual sensations, that the compound result comes to us as a unitary experience. Now this compound result: *an actual sensation, or actual sensations, supplemented by associations with past experiences, is known in psychology as a perception or a sense-perception.*

It has sometimes been stated that the difference between a sensation and a sense-perception is this that the latter has an object while the former has none. This is far from correct. A normal sensation has an external object just as a sense-perception has. But when we have a mere sensation—or more correctly, inasmuch as the conscious result of an actual sense-stimulus is a sensation,—*we merely experience an object, as it affects us here and now. This is the essence of a sensation.* There is more than this in a perception or a sense-perception.

As we proceed in our experimental inquiry we shall have to discriminate further between *a perception* and *a sense-perception* and define both more accurately. In fact we shall find that the compound result of a sensory stimulus is frequently a highly complicated mental process which should not be designated *in globo* either a mere "perception" or a mere "sense-perception." In this more complex process, however, either a "perception" or a "sense-perception," more accurately defined, always plays a part.

For the present we are not concerned with such finer discriminations. At this stage of our inquiry they would only bewilder the student. Hence for the present we shall not only use the terms "perception" and "sense-perception" indiscriminately, but both will be employed so as to cover every and any complex process initiated by a sensation. All we insist on now is that the term "sensation" should not be used for such a complex process, as we are wont to use it in our everyday speech. We frequently use the term "sensation," when we ought to say "perception"

or "sense-perception." All these terms are employed rather promiscuously. For the purposes of our everyday life this usage is accurate enough. But in the technical language of psychology we must of necessity make the distinction on which we here insist, *lest we ascribe altogether too much to sensations,* and treat as an immediate datum of our sensory experience what accrues to it only by a process of association.

No doubt a sensation, technically defined, seems unreal, an abstraction rather than a concrete reality. Not only does it seem to be, but it is. In fact this is the very point we mean to emphasize. We shall show experimnetally that a sensation in the technical sense never occurs alone in our normal adult experience. We must first isolate it artificially from other experiences which cluster around it and are welded with it into a seemingly unitary experience. Without some artificial process of isolation or abstraction we can never point to anything in our adult experience which answers the psychologist's definition of a sensation.

2. The Mediate Conscious Effects of Auditory Stimuli. We shall try to ascertain experimentally the mediate conscious effects of auditory stimuli. When the purpose of an experimental investigation like this is to make the finer discriminations above referred to, rather elaborate apparatus is sometimes used. But more important by far than accurate instruments are accurate observers. For self-observation is not easy. It requires a good deal of laboratory practice to make a detailed report of what we actually experience under standard conditions.

For the purposes of the following experiments no elaborate apparatus is required. Nor is accuracy in self-observation essential, though it should be aimed at. We may describe the experiences which supplement an actual sensation accurately or inaccurately; in technical or in untechnical language. We may be mistaken as to the finer discriminations above referred to. But no one that attends to any sensory stimulus can be mistaken as to the fact

that a sensation never occurs alone in our adult experience. There are always conscious processes which supplement it. Whatever else these supplemental processes may be, they are not actual sensations.

Experiment 108. No materials, then, of any kind are required for our present study of the effects of auditory stimuli. The hubbub of a city-street furnishes plenty of them. By selective attention pick out any one of the various noises that strike your ear. Observe carefully the conscious experience which results from it and report as accurately as possible what you experience here and now.

There is a peculiar sort of noise. What is your conscious experience? You say promptly: "I hear a street-car." If you are a good visualizer (we shall explain this more fully in the next chapter), you not only "hear" the street-car, as you say, but you also "see" it mentally, that is, you experience a visual memory-image of it. Possibly you may be able to tell its color. You may get, in addition, glimpses of its passengers, or even of people waiting at the corner of the street to board the car, and so forth, and so on. All these images, however, may be so fleeting as to easily pass unnoticed, unless you have already a good deal of practice in self-observation.

Perhaps the most accurate introspection does not reveal any such visual memory image of the street-car or of anything connected with it. Instead you may find that the word "street-car," even before it is actually pronounced, "rings already in your ears." You listen, as it were, to yourself pronouncing it. Or you may imagine yourself formulating the word with your vocal organs, and "have it at the tip of your tongue." In the next chapter we shall deal with such experiences more fully under the headings of "auditory" and "kinaesthetic word-images" respectively.

Nor is this all. For you not only *imagine* the word "street-car," but you *understand its meaning,* that is, you *"know" the object which is signified by the word.* In

fact this "knowledge" stands out boldly and unmistakably in the foreground of your attention. We shall have to discuss the nature of this "knowledge," and its relation to the imagery, later on. For the present we are satisfied with ascertaining the fact that you have this "knowledge."

The result of our analysis, then, is this: the actual sensation of the noise you attended to did not remain alone in your conscious experience. It was supplemented by the clear and unmistakable "knowledge" of the street-car, and possibly by visual images of it or of things connected with it, or by kinaesthetic or auditory images of the word, by which we arbitrarily manifest such "knowledge" and signify the object thus "known." Now this actual auditory sensation, supplemented by the conscious processes which accrue to it as a result of former experiences, we denote for the present *in globo* "a perception or a sense-perception." The auditory experience, initiating this complex process, and artificially separated from it, we call a sensation, pure and simple.

We may express the results of this experiment also by the following formula:

$$\text{A sense-perception} = \text{S} + (\text{s} + \text{s} + \text{s} + \text{s}) + \text{K}$$

In this formula the capital letter S stands for an actual sensation (or several actual sensations), aroused by the object present to the senses; each small s, for the revival of some sensation (visual, auditory, or kinaesthetic), aroused on a previous occasion by the same object or by others, connected with it; K, for the "knowledge" referred to, the nature of which will have to be investigated later; the sign of addition, for the process of association welding the various units into a seemingly simple mental act. The parentheses indicate that introspection frequently fails to reveal the units included by these parentheses. We shall find that the same formula is valid for all sense-perceptions.

Experiment 109. Analyse in a similar manner the experiences resulting from other auditory stimuli which you

pick out by selective attention. There is another noise. We shall call it noise 2. You report promptly: "I hear a dog barking." On listening to noise 3, your report is: "I hear an automobile," and so forth, and so on.

Now is it true that you "hear" all this? You express here in terms of sensation what is more than a sensation. In an unsophisticated attitude of mind you would not hesitate a moment to state all this—and probably much more—as immediate data of your sensory experience. You have "heard" all this with your own ears. As stated above, for the purposes of daily life we do not object to such a mode of speech, but in the technical language of psychology we say that you had "perceptions" or "sense-perceptions."

3. The Mediate Conscious Effects of Visual Stimuli. In the following experiments we shall study the mediate conscious effects of visual stimuli.

Experiment 110. Look attentively at the accompanying print (Fig. 72) held at a distance of about four feet away from you, and illuminated, preferably, by diffused sunlight from a window, at the left of the book. Can you see the print clearly? If so read the word, and describe your experience as accurately as possible.

Fig. 72.

You may say: Of course, I see the word "imagination." Its letters seem embossed. Are you sure you "see" the letters? The fact is, there is not a single letter there, least of all embossed. There are, however, hints of such embossed letters: actual shadows which would be cast by white letters, if the latter were illuminated from the left; this, and nothing else. But the hints, thus actually presented to our senses suffice for us to supply with our imagination what is not actually given by way of sensa-

tion. We need not state explicitly that these hints could not be effective without a good deal of previous experience.

Looking repeatedly at the print, we shall find that the supplemental images vary considerably in their vividness. At times they are so vivid, that we can trace clearly the white (illuminated) outlines of the embossed letters, that is, these imagined outlines assume almost the vividness of actual sensations. At other times they are much less distinctly "seen." At all times, however, our imagination supplies enough for us to read unhesitatingly "imagination".

Our experiment is typical of a number of experiences in our daily life which are likely to puzzle us. Thus for instance, teachers are sometimes wondering how in the world a pupil can read "grave" instead of "groove," "book" instead of "bake"—not to mention misreadings which seem positively outlandish. How can a pupil be so inattentive! The charge of lack of attention, however, is in most instances unfair. The simple fact is that a pupil even with a greater concentration of attention than the teacher himself gives to the reading, is much more liable to make such mistakes than the teacher. For occasionally such mistakes occur to all of us.

Most of us, in reading a printed page, pay little attention to the single letters, but take in whole words or even phrases as a unit and at a single glance. In other words, we treat words and phrases just as in our experiment we treated the single letters. A mere fragment of a word or phrase given in actual sensation, suffices as a cue for perceiving the whole word or phrase. This is especially the case, when we know beforehand the contents of the printed page and thus expect certain words or phrases to occur. Here the effect of "expectant attention," explained in the last chapter, comes into play. When the image of a word or phrase we expect to read is thus in readiness, especially if the rational context demands certain words or phrases,—then the combination of such an image with the fragmentary sensation is a matter of course.

The real difference between the pupil and the teacher does not—at least not necessarily—lie in the degree of attention which each gives to what is actually given in sensation. It lies in the fact that the store of past experiences from which the teacher can draw to supplement actual sensations into perceptions, is vastly greater than that of the pupil. The latter's mental furniture is rather poor. If the teacher demanded from himself that degree of attention to the details of the print which he is likely to expect from the pupil, he would not do much reading in his life.

Fig. 73.—(From R. Schulze, l. c.; Voigtländer's Verlag, Leipzig.)

Experiment 111. Look at the accompanying picture and describe your experience. There are but a few irregular patches of white in a uniformly black rectangular print. This is all the picture consists of. Your imagination will readily supplement these patches into a torch-light procession of children. The glare of the torches on the faces and clothes of the children is unmistakable. You "see" clearly how the little tot at the extreme left of the picture is led by the hand of the girl next to it. The outlines of the shaded portions of the torches—which are not there—can be clearly traced, and so forth, and so on.

Now cover with a piece of paper the head of the little

child at the extreme left, or cover the whole picture except the head of the same child, and you will realize what mere fragments of it are given in actual sensation. Note, moreover, how under these conditions your perception changes. For here again you have not a mere sensation but a perception. This perception, however, is now not one of a child, but of irregular patches of white paper on a dark field.

This experiment is again typical of what we experience a thousand times over in our daily life. The vast majority of our perceptions are formed in a like manner. If you were a witness of an actual torch-light procession of children, you would get by way of actual sensations no more, possibly less, than you get from this picture. All the rest is supplied by your imagination (cf. Schulze, Aus d. Werkstatt d. Exp. Psych. u. Ped., pp. 163 sqq.).

We should be in a sorry plight, if we had to see actually every detail of a house, tree, wagon, and so on, in order to form the perceptions of these things. In the light of our past experiences the merest fragments of these things, given in actual sensations, will touch off the supplementary processes rounding them out into perceptions. Just look out of the window, and find out how much, or rather how little, you actually see of a distant house, tree, or wagon. It is only when an unusual object is presented to our eyes, that its details must be actually sensed. We would not perceive much in the course of a day, if we could not draw on the store of our past experiences.

Experiment 112. Observe objects in your room or any objects in space around you *monocularly,* and note the vividness with which you perceive the distances of objects from one another. It is hard for us to realize that this vivid experience is under these circumstances not a sensation, but accrues to our actual sensations only as a result of former experiences. And still so it is, as we have seen in chapter IX.

4. The Mediate Conscious Results of Tactual Stimuli.

Experiment 113. Close your eyes and touch some object on your table or in your room. If the object is a familiar one, your first touch of it, say with the tips of the thumb and forefinger, will result in the perception of a pencil, a fountain-pen, an ink-stand, a book, and so forth, and so on. Note here again, how little of such objects need be given in actual sensation. All the rest is supplied by revivals of past experiences.

If the object touched be one that we have rarely handled, seen, heard, or experienced in any manner whatever, our first touch of it will arouse only the perception of "something, we know not what." To acquire a more definite perception of the object, we must handle it more carefully, that is, explore its various surfaces with our fingers or the whole hand, or possibly with both hands. When a number of tactual sensations thus combine, they may recall also a visual memory image of the object or some other past experience connected with it. Only then may we know in particular what the object is.

Note also the fact that it is two discrete touch-sensations which—in this experiment—initiate the perception of one pencil. This insignificant item of information will acquire greater significance in a future experiment which is at first puzzling.

5. Sense-Illusions. Ever since the time of the Greek skeptics sense-illusions have been a stumbling-block to some philosophers in their discussions anent the veracity of the senses. Though we are not directly concerned with such discussions, the experiences which occasioned them are of great psychological interest. For sense-illusions are most intimately connected with the subject of sense-perceptions and have in this connection received a good deal of attention on the part of modern psychologists. In the light of our subsequent investigation we shall find that the term "sense-illusion" is, strictly speaking, a misnomer. The experiences, thus designated, have nothing whatever to do

with the veracity of the senses. It is only when we confuse a perception with a sensation that the famous difficulty can arise.

We have seen that the greater part of the processes, known *in globo* as a sense-perception, accrue to an actual sensation only by association with past experiences. Moreover, the more familiar an object is, that is, the oftener it has occurred in our past experience, the less is required by way of actual sensation to initiate its perception.

This premised, a little reflection will show that one and the same sensation, pure and simple, may be aroused by many different objects in nature. Not everything that glitters is gold. There are many things which look red, or cause under appropriate conditions the same noise, or feel pretty much alike to the sense of touch. This is particularly the case, when we get only mere fragments of these objects by way of actual sensations.

One and the same sensation, then, has been associated in the past with many different experiences. Which now of its many associates will be aroused, when the same sensation occurs again in our experience? This will depend on the condition of our attention which, as stated before, dominates our whole conscious life. *If we allow our mind to run in its habitual grooves, of course, the most habitual associates of a definite sensation will without fail cluster around it when the sensation occurs again. And this is the first source of sense-illusions.* For though these associates are in the majority of cases the right ones, ever and anon the case will arise when they are the wrong ones. And then we have a perception which is a sense-illusion. *Another, and even more fruitful source of sense-illusions is "expectant attention"* (cf. James, Psych., p. 318). We have dealt sufficiently with the latter in our chapter on attention (cf. Ch. XIII, n. 9, Exp. 102, p. 231). The following little experiment, which has the distinction of being the first one recorded in psychological literature, illustrates the first source of sense-illusions.

Experiment 114. Aristotle's Illusion. Aristotle, discussing the origin of sense-illusions in his treatise "On Dreams," notes the fact that a single object, touched with crossed fingers, appears to be two. You can convince yourself of this by crossing the middle- and forefinger, and running a pencil between them up and down. If you get hold of the tip of your nose with the fingers thus crossed, you cannot resist the ludicrous experience of two nose-tips, all the more realistic, as your sight cannot interfere with the illusion.

Now what really happens in this illusion? By crossing the fingers, and running a pencil between them, we touch the right side of the middle-finger and the left side of the forefinger with one and the same pencil, as will be seen from Fig. 74. Under ordinary conditions these two portions of the skin are never touched except by two objects, say two pencils or two prongs of a fork. This will be seen from Fig. 75. The two touch-sensations, accordingly, arouse habitually the perception of two things. Under the unusual

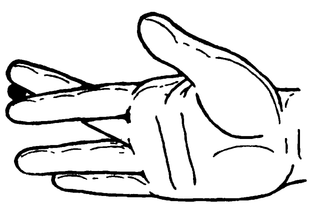


Fig. 74.

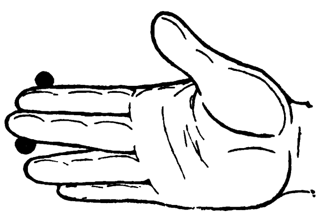


Fig. 75.

conditions of our experiment the same habitual associates cluster around the same two touch-sensations, and we have again the perception of two things. The habitual associates, however, are here and now the wrong ones, and thus arises the sense-illusion.

Experiment 115. The Converse of Aristotle's Illusion. If our account of Aristotle's illusion is correct, it should be possible to bring about the converse illusion, namely, that of one object, when our crossed fingers are touched

by two. Try the following simple arrangement and find out for yourself.

Double up a heavy string and slip the loop over a nail in the wall, holding the loose ends of the string—now really two strings—tightly stretched in the left hand. Cross the fore- and middle-finger of the right hand as in the preceding experiment, and run the tips of the two fingers between the two strings up and down. Do not look at the operation. Only make sure that the lower string presses against the right side of the fore-finger and the upper string against the left side of the middle-finger, as indicated in Fig. 76. So doing you will have the illusion of one string between the two fingers. According as we vary the position of the fingers, the string seems straight or bent.

The reason for all this is clear. For it is the same two touches—that of the right side of the fore-finger and that of the left side of the middle-finger—which habitually result in the perception of one string between these fingers. This will be seen from Fig. 77 which represents the habitual conditions of our perception of one straight string. When

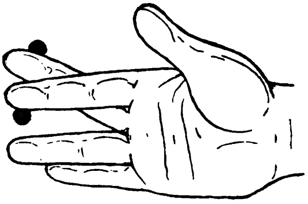


Fig. 76.

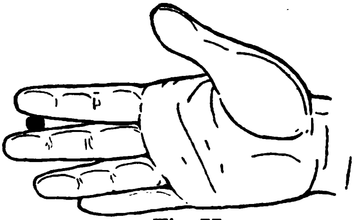


Fig. 77.

the latter is really bent between the fingers, the two areas of the skin touched by it differ somewhat, but they are again the same as are stimulated in the experiment, when the string seems bent.

6. The term "Sense-Illusion" is, strictly speaking, a misnomer. By way of digression just a word as to the criteriological aspect of these and similar sense-illusions. Note, first of all, that there is absolutely nothing wrong about the two touch-sensations which initiate Aristotle's

illusion. Two portions of the skin are touched by one pencil, and we have two touch-sensations. If they remained two touch-sensations, pure and simple, our discussion would be at an end. For so far there is nothing wrong. *What is wrong is supplied by the supplemental processes,* rounding them out into the perception of two pencils.

Even among the supplemental processes there is really only one which is wrong: it is the *judgment* that the two sensations are aroused by two pencils. All the other processes, such as visual images of two pencils, or even the mere intellectual apprehension of two pencils, contain nothing wrong of themselves. What is there wrong about the visual image, or the intellectual apprehension, of twenty dollars in my pocket? The mistake occurs only when I do more than merely imagine or apprehend them, when I *judge* that a have twenty dollars in my pocket. For the fact is, I have them not.

Error, as every tyro in logic knows, can be found only in a judgment. A mere image and a mere apprehension of an object are not *judgment.* Still less is a sensation, pure and simple, a judgment. Consequently, if it be said that in Aristotle's experiment and in experiences of a similar kind our senses err, the answer is: *our senses do not err for the simple reason that they do not judge.*

7. **The Physiological Factors of Sense-Perceptions.** Our criteriological digression is all the more pardonable as it serves also a useful psychological purpose. You realize now in a concrete example what we said in the beginning of this chapter, namely, that the processes supplementing an actual sensation are sometimes extremely complicated. They consist not merely of memory-images of various kinds but also of intellectual apprehensions and, not unfrequently, of judgments and reasoning processes. We have termed all these heterogeneous processes, together with the initial sensation or sensations, a "perception" or a "sense-perception." Evidently there is need of finer discriminations.

Certain psychologists have made their task of explaining all these mediate effects of sensory stimuli a very easy and simple one. In this explanation, however, facts and theories are peculiarly intermingled; some facts are unduly emphasized, others are glided over with a remarkable ease and unconcern. As the very simplicity of an explanation makes it irresistibly attractive, the student should realize clearly what in the explanation is fact and what is theory, and he should ask himself whether all the pertinent facts have been duly considered. We shall begin with some fundamental facts of nerve-physiology and their bearing on the problem of sense-perceptions.

Actual sensations leave traces or records of themselves in the nervous system. Once a sensory centre in the brain of a new-born babe has been acted upon by a sensory stimulus, this centre is in a different condition from what it was in before. The neural excitement into which it was thrown ceases indeed when the stimulus is withdrawn, but it can be thrown more readily into the same excitement the second time, and still more readily the third time, and with the greatest ease the hundredth time.

This item of nerve-physiology is undoubtedly correct and it is because of such a record, left in the brain-centres, that former sensations can be aroused again even in the absence of their actual stimuli. At least this is one of the factors of the revival of former sensations and is known by the name of "the perseveration of sensory experiences."

Moreover, *when different sensory experiences have occurred together or in immediate succession, any one of them, on re-occurring, tends to revive the others also.* This is the principle of sensory association, which—as here stated—is undoubtedly correct. The physiological basis of it is this. The brain-centres of all the senses are connected not only with the peripheral sense-organs but also among themselves. The result is that the physiological excitement created in one brain-center—say in the visual centre—can be propagated to all other centres. The fibres connecting the various centres with the peripheral organs are

known as "projection-fibres," those connecting the centres among themselves, as "association-fibres." When two sensations occur together or in immediate succession, the neural current will actually flow from one centre to the other and thus a definite path is established. Once this has taken place, the neural current passes through it more easily the second time. The more frequently two actual sensations occur together, the deeper will the neural groove be and the more readily will the neural current pass along this groove, even in the absence of external stimuli. Thus it is that out of millions of possible paths definite ones gradually become firmly established.

Let A, B, C, and D represent four sensations, associated at some time in our past experience either simultaneously or in immediate succession. If now any one of them, say B, occurs again as an actual sensation, it will *tend* to revive also its former associates: A, C, and D. We say it "tends" to do so. For the actual revival of A, C, and D, may encounter difficulties. When revived, they constitute a sensory-image or a combination of such images. This again, as stated here, is correct.

8. **Sensationalism and Associationism.** We come now to assumptions and sweeping generalisations.

If other sensations also, say E, F, G and H, have been associated at some time with the same sensation B, which one of its former associates (A, C, D, E, F, G, H,) will be here and now revived? This—we are told—will depend *exclusively* on the relative depth of their respective traces in the brain and on the relative strength of their interconnection. Some tracts are more pervious than others. The neural current follows the line of least resistance, that is, along the more pervious tracts. The revival of sensations depends on the neural currents. As a result the actual sensation B will arouse C, F, and H, on one occasion; A, D, and G, on another occasion, and so forth, in accordance with the concrete neural conditions on each occasion. This sweeping generalisation means in plain and

outspoken terms that *voluntary control over our perceptions—in fact over our whole mental life—is categorically ruled out.* If such voluntary control is referred to, as is done at times by sensationalists themselves, this term is understood to be strictly a misnomer.

We said "over our whole mental life". For the fundamental assumption is made that *sensations are the constitutive elements of all our cognitions, also those familiar to us as intellectual operations.* Accordingly it is sensory images, and nothing but sensory images, of which the mediate results of actual sensations consist. Our whole mental life is but an ever-changing pattern which arises from the combination, liberation and substitution of elementary sensations (and feelings). *This is the very essence of sensationalism.*

If this assumption be correct, it follows that the most heterogeneous processes—or what seem to us such—*images of fancy, judgments and reasoning processes, are governed, one and all, by the same law of sensory association.* In fact the principle of sensory association holds the same place in psychology as the law of universal attraction in physics. *This is the very essence of associationism.*

The law of sensory association, moreover, is in its last analysis but *a law of neural habit* and can, therefore, be expressed *in purely physiological terms.* In its broadest outline it may be stated as follows: "*When two elementary brain-processes have been active together or in immediate succession, one of them, on re-occurring, tends to propagate its excitement into the other*" (James, Psych. p. 256). When we ask for details, the formula runs as follows: "*The amount of activity at any given point in the brain-cortex is the sum of the tendencies of all other points to discharge into it, such tendencies being proportionate (1) to the number of times the excitement of each other point may have accompanied that of the point in question; (2) to the intensity of such excitements; and (3) to the absence of any rival point functionally disconnected with the first*

point, into which the discharges might be diverted'' (l. c. p. 257).

9. We insist on testing these assumptions and generalisations, before accepting them.

Such is in brief the theory of the aforesaid psychologists concerning the origin and nature of perceptions. Like every other theory, it must be judged in the light of facts and we cannot accept it *in globo* untested. *For the present we are satisfied with challenging the following points:*

(1) The contention that all the mediate effects of sensory stimuli, intellectual apprehensions, judgments, and reasoning processes included, consist of nothing else than revivals of sensations and their combinations by way of association. In other words we challenge the fundamental assumption that sensations are the constitutive elements of all our cognitions.

(2) The contention that our intellectual operations are dependent on definite nerve-processes in exactly the same way as this is true with regard to sensations.

(3) The contention that our whole mental life, the whole course of our ideas, follows always and without exception the line of least resistance.

These three assumptions are, to say the very least, not self-evident; neither *a priori,* like the proposition: twice two is four; nor on the basis of unmistakable experience, like the proposition: the light of day comes from the sun. To unsophisticated minds, in fact, they are rather surprising. *We insist on testing such sweeping assertions in the light of experience.* There is accordingly a good deal of experimental work ahead of us, before we shall have finished our experimental analysis of the mediate effects of sensory stimuli. This finer work will be dealt with in later chapters. All we insist on for the present is that we keep our minds free from all sensational bias.

Missourians have a refreshing peculiarity: *they ''want to be shown''.* The reader may, or may not, be a Missourian. But in the question of sensationalism we

should be Missourians. Then we are in the right frame of mind to accomplish successfully some of the experimental work of our next chapter, which is fundamental in this regard.

10. A Sense-Perception, More Accurately Defined. There is, however, one process which we are able to define more accurately in the light of the experimental work done so far. It is the one which we shall call "a sense-perception" in the strictest sense of the word. We define it as *an actual sensation, or actual sensations, aroused by a present object, and supplemented by unmistakable sensory images of the same object, that is, by revivals of former sensory experiences of the same object.* At times, at least, an actual sensory experience of an object does revive former sensory experiences of the same object, and that in a manner which is unmistakable. This happens, for instance, when, on experiencing the scent of a rose, we recall also an unmistakable visual image of it. When this occurs, we have a "sense-perception" in the strictest sense of the word. It is identical with what in Scholastic terminology is known as an *"actus sensus communis"*. The term *"sensus communis"*, it should be added, is far from being synonymous with what in ordinary parlance goes by the name of "common sense".

We may now also improve on our preliminary formula of a sense-perception and say:

A sense-perception in the strictest sense $=$ S $+$ s $+$ s $+$ s. In this formula S stands for an actual sensation or actual sensations, aroused by a definite object present to our senses; s $+$ s $+$ s, for the revival and association of sensations aroused on a previous occasion by the same object. The absence of the parentheses denotes that these revived sensations are unmistakably present. K of our former preliminary formula is absent, not because K itself is absent in our experience, but because we "want to be shown" that it, too, is resolvable into s $+$ s $+$ s.

11. A sense-perception, thus acccurately defined, never occurs alone in our adult experience.

We began this chapter by saying that a sensation in the technical sense of the word never occurs alone in our adult normal experience. The same thing must now be said of a sense-perception, as above more accurately defined. For we must artificially separate the above units of our formula from K without which they never occur in our experience. It is not pleasant to finish an experimental investigation of a subject with a question mark. Willy-nilly we must do so here by asking: *What is this mysterious K?*

CHAPTER XV

IMAGINATION

1. The Popular and the Technical Use of the Term "Imagination." The subject of imagination follows naturally and without break upon that of sense-perception. In fact, some aspects of the two subjects are identical and have already been dealt with in chapter XIV. This is our excuse for some unavoidable repetitions.

The first thing, then, to be noted about "imagination" is that this term, just like that of "sense-perception," is employed rather loosely in our everyday language. Even in scientific and philosophic discussions we are wont to follow this common usage, whenever there is no danger of misconstruing the term into something which we never meant to express.

Thus, for instance, we say that we cannot "imagine" what causal connection there may be between two ascertained facts of experience, and we declare our "imagination" bankrupt to conceive the infinity of God. We ought to say instead that we cannot "conceive" or "reason out" the causal connection of the two facts, and we ought to declare our imagination bankrupt to deal with anything whatever that has not at some time or other been an immediate datum of our sensory experience. What we really mean is that we cannot form an intellectual representation of this or any other attribute of God in proper terms but only by means of analogous concepts derived from creatures.

Technically employed, an act of imagination or "an image" is nothing else than *the revival and the association of former sensory experiences of an object which is not now actually present to our senses.*

It has also been defined briefly as *"centrally aroused sensations"*, that is, internal sensations, not initiated by

the excitation of a peripheral sense-organ, but by some internal excitation of a brain-centre, and thence propagated to other centres, as happens, for instance, in many dreams.

The former definition, however, is preferable. For apart from the fact that a goodly portion of a sense-perception is also centrally aroused, there are many true images which are aroused peripherally. Thus, for instance, I need only pronounce the word "street-car", and you may experience in consequence a visual image of the object in nature thus designated. This image is undoubtedly due to the sound of the word, that is, it is aroused peripherally. The process, however, thus initiated is not a sense-perception, but a true image, because it is not aroused by the object itself, as was the case in experiment 108, and as we require in the definition of a sense-perception, strictly so called, (p. 262), but in the absence of the object, merely by the sound of my voice. This sound has of itself no more connection with the street-car than the stars in the heavens have. It has, however, been associated in the past with the visual sensations whose revival constitutes the said image of the street-car, just as firmly as the noise of the street-car itself. Hence one and the same image can be aroused just as well by the former as by the latter. It should be added that, once the image is thus aroused, the word itself remains no longer in the focus of attention.

2. Mistaking Images for Sense-Perceptions, and Vice Versa. We see form this that *an image and a sense-perception are processes which are very much akin,* if we compare the two *merely psychologically,* that is, merely as facts of internal experience, and *not from the standpoint of logicians.* The main psychological difference between them is that an image is, as a rule, much less vivid than a sense-perception. We say, as a rule. For this difference is far from being universal and thoroughgoing, as we shall see presently. Hence the possibility of mistaking one for the other.

In cases of doubt we rely on criteria which logical con-

siderations furnish us. The principal criterion is that pointed out by Aristotle, namely that it is not in our power to have a sense-perception, when we will. To perceive an apple, an apple must be present. In its absence no effort of my will suffices to bring about the perception of an apple or an experience which under normal conditions could be mistaken for such a perception. The image of an apple, however, depends, at least to a great extent, on our will. I can make up my mind to imagine an apple.

Under ordinary conditions the application of this criterion is easy enough. There are, however, cases in which its application is very puzzling.

When images are unusually vivid, and the voluntary control of our mental life is in abeyance, they are easily mistaken for sense-perceptions. This occurs regularly to all of us in ordinary dreams and not unfrequently in the transitional states between waking and dreaming. This fact is familiar to every one. The hallucinations of patients in fever-delirium and of drug-victims under the influence of opium, hashish, or belladonna, are the most striking illustrations of this kind.

A similar difficulty arises, when the actual sensory stimulus, initiating a sense-perception, is so faint as to be near the threshold of sensation. It has probably occurred to many readers that, on awakening at night, they began to count the strokes of a distant tower-clock, and continued to do so, really not knowing any longer whether they actually heard the clock or only imagined it. Similar experiences could easily be multiplied.

A remarkable series of experiments was carried out in the Cornell laboratory in demonstration of the same difficulty. The experimental arrangement used is altogether too elaborate to be described in detail here. (Cf. Am. Journ. of Psych., 1910, pp. 428 sqq.) Suffice it to say that a great many preliminary tests of the apparatus used had to be made, in order to secure their appropriate handling during the experiments proper. For the latter numerous

observers were employed, some of whom had considerable practice in laboratory work. Each observer was seated in a large, well-lighted laboratory and opposite the ground-glass window of a dark-room which was situated in the middle of the laboratory. He was instructed to fixate a definite white spot on the ground-glass window and to make a deliberate effort to imagine a familiar object indicated by the stimulus-word, say *a tomato,* and to keep fixating said white spot while producing the image.

Simultaneously with the presentation of the stimulus-word the experimenter signalled to two other experimenters, hidden in the dark-room. The latter then exposed and very gradually illuminated a transparency which exhibited the color and form of the object, signified by the stimulus-word. In other words the two hidden operators presented to the observer an actual faint stimulus, such as would have been made by the object itself, say a tomato. The electrical signalling apparatus was so carefully concealed and handled so skilfully that the observers did not suspect anything of this elaborate arrangement. In a similar manner each observer was asked to imagine a book, a banana, a lemon, a leaf, and an orange, and corresponding transparencies were simultaneously exhibited and gradually illuminated.

Because of an error in the technique some observers became aware of the experimental arrangement, and they were promptly eliminated. In all the other observers the result was uniformly the same: *they all mistook the actual sense-perception for an image,* and this in spite of the fact that the actual stimulus was appreciably above the threshold-value.

It is worthy of note that in some observers imagery and sense-perceptions were peculiarly intermingled. Thus one, who had had long experience in the laboratory, reported that he imagined the tomato, as painted on a can; the book as a particular one, whose title he could read; the lemon was lying on a table; the leaf was a pressed one with red

markings on it. Some saw an elm leaf, when they had been trying for a maple leaf (l. c. p. 432).

When at the end of the experiments each observer was asked whether he was "quite sure that he had imagined all these things", the question almost always aroused surprise and at times indignation (l. c. 431). On the other hand, after the experimental arrangement was explained to a number of the observers—they were graduate students—"they invariably recognized the appearance of the stimulus at or before the point, at which they had previously reported an image" (l. c. p. 430). They as well as some competent visitors could hardly believe that stimuli so "ridiculously real" had been mistaken for images (l. c. p. 450).

These experiments confirm what we stated above, namely, that *psychologically there is no thoroughgoing difference between an image and a sense-perception,* and that the latter can be easily mistaken for the former, when the actual stimulus is near the threshold-value of sensation.

3. Reproductive and Creative Imagination. When imagining an object, we at times merely reproduce the sensations which that object has produced in us in the past on the same or on different occasions. Then we have what is known as an image of sensory memory or simply a memory-image. (It is well to add that a memory-image is by no means identical with that complex experience which we shall discuss in a later chapter under the heading of memory.) The image of sensory memory, then, is a faithful copy of the object as actually sensed, a second edition, as it were, of our original sensory experience of that object. This statement, however, must not be construed to mean that we always reproduce every detail of the object sensed, nor that the revival of past sensations is peculiarly vivid. If this were required, few persons could boast of memory-images. But no sensory experience derived from other objects, may be incorporated into the image. Only in this

sense is a memory-image a faithful copy of our former sensory experiences (cf. Am. J. of Psych. l. c.).

Frequently, however, we combine in various ways the sensations produced in the past by different objects. This occurs—to use the traditional and somewhat grotesque example—when we combine the visual impression made by the head, arms and chest of a man with that made by the body and legs of a horse, thus creating the appearance of an object which does not exist in nature, namely, the image of a centaur. This is known as an image of fancy, and our ability to form images of this kind is known as creative imagination.

It is well to add that the grotesqueness of the illustration used is a very unessential feature of an image of fancy. Whenever we are not faithful, as explained above, in copying sensory impressions of an object in nature, as when we "idealize" natural objects for artistic purposes, we make use of creative imagination.

From this description of creative imagination it will be seen that this term does not imply the arousal, by the mere fiat of the will, of internal sensations which have never occurred in our past experience as actual sensations. Such a thing is simply impossible. If we have never heard an oboe, we cannot, by a mere fiat of the will, imagine a melody as played by an oboe. And still we can with more or less success "create" such an image, provided we have had auditory experiences enough and are capable of recalling and combining them, that is, provided we have auditory imagery at all.

When a familiar tune is played on a violin, you may be able to reproduce this auditory experience. Then you have an auditory memory-image of it. The melody, as played by an oboe, is the same, as far as the pitch of each tone (say c'') and its loudness (say *mf*) is concerned. The distinctive character or clang-tint of each note, however, is different from that of a violin-tone, in fact, from that of every other instrument. The tone of an oboe is remarkably mellow, somewhat nasal and penetrating, plaintive

and idyllic. This description may recall sensory impressions of other sounds in your past experience which in part, at least, answer this description. Putting all these sensory experiences together you may make a fair approach at "creating" an image of a melody as played by an oboe. It is the *facility* in thus recalling and appropriately combining various sensory experiences of the past, which constitutes the talent of a musical composer, poet, painter, and all other artists, and enables them to "create" their works of art.

4. The Factors of both Reproductive and Creative Imagination. If we now inquire, what factors determine either the faithful recall or the fanciful combination of former sensations, sensationalists recognize but two. We explained them, when discussing the images supplementing our actual sensations into sense-perceptions. They are 1) the perseveration of sensory impressions, and 2) the force of sensory association. In other words *sensationalists rule out entirely voluntary control as a factor of imagination,* or if they use the word, it is understood to be strictly a misnomer. Consequently it is in every instance simply a question of what the line of least resistance is, whether we experience a memory image or one of fancy, this image or that.

Undoubtedly the two factors of sensationalists are at work, and at times they are the only ones at work. Who has not experienced images of both kinds coming to him unbidden, and he knows not whence,—in fact, in spite of himself? If you have worked all day in the laboratory with the color-wheel, you will find in all probability that at the fag-end of the day you see nothing but disks, and that with a surprising vividness. You need not be an accomplished musician to experience snatches of this or that air of an opera you have just listened to, running through your head, now as faithful copies of what you have heard, now combined into strange medleys. Willy-nilly you must listen to these haunting melodies.

Likewise after laboratory exercises in memory you may find that fragments of this or that series of nonsense syllables, intermingled with disconnected portions of various poems, return to your mind irresistibly and in parrot-like succession, just as you compose yourself to sleep. On such occasions, with sleep so near and yet so far away, one would wish that the psychologist, who has set the machinery of association a-going and has imprinted the brain-records according to the most improved methods, could also stop the annoying machinery. *"Die ich rief, die Geister, werd' ich nun nicht los". (The spirits whom I called I cannot quell.)* In such a predicament the best advice is to make up our minds deliberately, neither to further nor to hinder the spontaneous flow of images and to be, as it were, inert spectators and listeners until the excitement is spent. This is the only remnant of voluntary control which then remains practicable.

A similar condition prevails when we are under the influence of strong emotions. Then the machinery of association fairly runs away with us. If no effort to divert our attention from the images is successful, the same advice will be of service to accomplish the desired result.

The most absolute and uncontrolled sway of the two factors of imagination, just as they are postulated by sensationalists, obtains in fever-delirium and in the brain-storms of drug-victims.

It is, however, only fair to say that we are not always in the same condition as at the fag-end of the day, nor always under the influence of strong emotions. Even in the drug-victims the brain-storm subsides some time and they have lucid moments, when the normal control of their mental faculties returns. And under such normal conditions voluntary control is an unmistakable factor, determining the appearance and course of our imagery.

If it were not for this control which we exercise over our images, it would be absurd for me to expect the reader or the members of the class to follow me in the present discussion. For to do so, they must suppress many an

irrelevant image, aroused by the machinery of association, and call up many other images which do not lie along the line of least resistance.

Every laboratory experiment on memory-images or those of fancy is an experimental demonstration of that factor of imagery which sensationalists wish to see ruled out in the interest of their pet metaphysical theories. If the subject of a psychological experiment does not want to carry out instructions, when told to call up an image, say of a house, a banana, or anything else, according as the experimenter may direct,—or if he resists the appearance in his mind of images, called up by the machinery of association, by deliberately directing his attention to other things: we can do nothing with him in the psychological laboratory, in fact in no laboratory of any kind.

The most conspicuous mark that distinguishes laboratory observations from those of ordinary life is that they are controlled by the arbitrary choice of the experimenter, and in the case of psychological experiments, *by the arbitrary choice of both the experimenter and the subject,* each in his own sphere. It is simply suicidal for a psychological experimentalist to deny voluntary control over our imagery in the interest of his pet metaphysical theories.

No doubt, such voluntary control is mysterious. So are a thousand other facts in psychology and in all other sciences. But it will not do to deny a fact because it is mysterious. We had better take facts just as they actually occur. If they do not agree with our pet metaphysical speculations of how facts ought to be, so much the worse for these speculations. Accordingly, taking experience for our guide, we recognize voluntary control as a most important factor of both memory-images and those of fancy.

5. **Images and Voluntary Movements.** The subject of voluntary control over our images leads us naturally to another aspect of imagination, namely, the part it plays in the acquisition of voluntary control over our body. We

shall deal with this topic in a future chapter, when discussing the various modes of "learning". For, among many other things, we "learn" also skilled movements. Thus, for instance, we learn writing, typewriting and piano-playing, and more particularly those extremely complicated movements in comparison with which all other "skilled" movements dwindle into insignificance: those of oral speech. It must suffice here to have called attention to this aspect of imagination.

6. Sensationalism Again. There is, however, one aspect of imagination which we cannot leave out of consideration on any account: its connection with thought. So intimate is this connection that the popular use of the term imagination has its main root here. And the hypothesis of sensationalism could never have been proposed with even a semblance of foundation in fact, if it were not for this connection. In order, then, to finish our account of both sense-perception and imagination, *we must of necessity face the problem of sensationalism.* We are about to do so now, but only in as far as this is needed to complete our account of sense-perception and imagination.

We shall meet the same problem, or other aspects of it, again in almost every one of our future chapters. If, therefore, we were to leave the question as to the nature of thought open until we reach the chapter on the thought-processes, we should be continually hampered. Every chapter preceding that on the thought-processes would have to end with a question-mark, as did our last chapter on sense-perception. Happily we can avoid this by *separating the fundamental proposition of sensationalism from the details of its application.*

The fundamental proposition of sensationalism, as the reader will remember, is this: *any and every process which goes popularly by the name of "thought" is reducible to sensations as its constitutive elements.* If this sweeping generalisation is true, then it makes no difference what particular thought-process we strike in our present inves-

tigation, nor what its distinction from other thought-processes may be. All we have to find out by experiment is, whether this particular thought-process is reducible to sensations. If yes, sensationalism stands as a working hypothesis. If no, then sensationalism, as a sweeping generalisation at least, cannot be accepted, although we may have to consider—and shall consider—how it works, when applied to particular problems.

By proceeding, then, in the manner proposed, there remains plenty of work to be done in our future chapters and every one of them as well as the present chapter will be a complete account of the respective subject under discussion.

7. Two Fundamental Facts concerning the Relation between Images and Thought. Modern experimental methods have revealed two facts concerning the relation of images to thought which are of paramount importance in settling the *fundamental problem* we have set ourselves.

The first fact is that different persons differ considerably with regard to the images which they experience when thinking of one and the same object. On the basis of these individual differences persons have been arranged into groups, each said to possess a peculiar "type of imagination". This aspect of the first fact will be dealt with in a later paragraph. Here it is of importance to note that *the doctrine concerning the so-called "types of imagination", whatever may be its further psychological significance, expresses only a part of the first fact, here emphasized.* For even persons belonging to the same type differ considerably as to the details of their images when thinking of one and the same object.

The second fact is this. In one and the same individual images vary considerably with the concrete conditions in which he finds himself, so that there is hardly any one who experiences on two successive occasions the same images in every detail when thinking of one and the same object.

8. Experimental Verification of these Two Facts. Various methods may be employed to ascertain these two

facts. *Memory experiments* furnish excellent material in this regard. Accordingly we shall return to the present subject incidentally in our next chapter.

Another method is to make *a statistical inquiry* like that begun by Galton in 1880. He addressed a circular to a great number of persons, requesting them to describe accurately the visual imagery they experienced, when thinking of their breakfast-table on a definite morning. The individual differences which the answers revealed were found to be astonishing.

Other investigators have prepared detailed *questionnaires* concerning images, mainly with a view to determine the so-called type of imagination to which each individual belongs. Such, for instance, is the questionnaire, proposed by Prof. Titchener in his Experimental Psychology (Vol. I., pp. 198 sqq.).

The following class-exercises are variations of this questionnaire-method. *Their scope, however, is much wider than that of the said questionnaires.* Simple as these exercises are, they are very instructive if properly conducted.

Experiment 116. The instructor selects a word signifying a familiar sensible object, such as *street-car* or *automobile.* Words signifying objects which of their very nature cannot be presented to the senses, such as *justice* or *law,* should be avoided. Of course, we can also investigate the images which we experience, when thinking of such objects. But these images and their connection with thought deserve special consideration and will be dealt with in the chapter on thought. In this and all the following exercises we restrict ourselves to *such conditions as are most favorable for the sensationalistic hypothesis.*

The instructor proposes the word selected to the whole class *by simply pronouncing it.* As soon as this is done, every member of the class is to think with concentrated attention of the object signified by the word, and to make a deliberate effort to recall any *visual* experience which

the object has aroused in the past. To secure this concentrated attention, about two seconds before the instructor presents the word, he should indicate this by the simple warning "Ready!" As images proper, worthy of the name, are sometimes very slow in making their appearance, comparatively long after the meaning of the word has been understood, fifteen seconds should be allowed for arousing such images. At the expiration of this time each student should answer the following questions in writing:

1) Did you understand the meaning of the word, that is, did you know the object which is signified by the word? 2) What visual images arose in your mind during the fifteen seconds of the exercise? 3) Did auditory or kinaesthetic images present themselves unbidden? 4) Did you experience verbal images?

PRELIMINARY INSTRUCTION TO THE STUDENTS

Before the exercise proper each student should *familiarise himself perfectly* with the following instruction as to what he is expected to answer to the single questions.

In the first question you are *not* asked whether you experienced *imageless thought.* Possibly your thought of the object is, after all, only *a peculiar constellation of images* and you are not called upon to decide this problem by simply answering the first question. None of all this. The answer which you are expected to give is an extremely simple one. Suppose you were ordered to buy an apple. If you are able to carry out this order intelligently, then *you have understood that which is signified by the word apple.* Hence, if "apple" is the word, used in this experiment, then in answer to the first question you can say conscientiously: *"Yes." Your answer is altogether non-committal.* If, moreover, you experienced this knowledge immediately upon hearing the word, you add: *"Promptly."* If, however, it took an appreciable time until this knowledge dawned upon you, then you add: *"Slowly"* or *"Very slowly,"* as the case may be.

The other questions are no examination-questions. The instructor does not want to find out how much you know about the sensible qualities of the object. *The second question, in particular, is whether you actually saw again with your mind's eye the object of which you were thinking, that is, whether you succeeded in reviving some visual sensations which the object aroused in you in the past.* If so, you should also indicate briefly whether these revived sensations were *complete and detailed* or only *fragmentary* as to the colors of the object or its shape or both; whether they were *vivid* or only *dim and shadowy; persistent* or only *momentary and fleeting; prompt* or *slow* in presenting themselves. Besides—or perhaps instead—you may have experienced visual images of *other* objects, connected in any manner whatever with that of which you were thinking. *Possibly the most outlandish images crowded in upon your mind.* If so, state just what you have actually "seen."

As to the third question note that during the exercise you are not to make any effort to arouse auditory or kinaesthetic images. Your whole attention should be concentrated upon one thing: to "see" the object of which you are thinking. To secure this concentrated attention try to see more and more of the details of the object. But perhaps, while thus trying to visualize the object, you could not help "hearing" (with your mind's ear) the sounds made by the object or by others connected with it. Such are *auditory images,* and in this instance they would be *spontaneous.* Or, again, you may have found yourself, as it were "handling" the object, thus experiencing again its smooth or rough surfaces, its heat or cold, or the movements of your fingers, hands, arms, or the whole body. Such are *tactual and kinaesthetic images,* and in this instance, they would be *spontaneous.*

In answer to the fourth question you are to report whether instead of, or besides, the above images, you heard, for instance, the voice of the instructor still ringing in the ear; or whether you saw the stimulus-word written on the black-board or printed in a book; or whether you had

the word, as it were, at the tip of your tongue. Such are known as *auditory, visual, and kinaesthetic word-images* respectively, and in this instance they would be *spontaneous.*

You get only five minutes for writing your report. Make no attempt at style. Simply jot down as quickly and briefly as possible the actual experiences which you had during the 15 seconds of the exercise, *while these experiences are still fresh in your memory.* Do not add to your report what you experience now, while writing the report.

Experiment 117. A similar exercise should be performed by the members of the class with the instruction to make a deliberate effort *to arouse auditory images of the object thought of.* The stimulus-word should be the *same* as in the last experiment.

In answer to the second question an introspective report is to be made of all auditory images which have been actually aroused during the 15 seconds of the exercise. The students must be warned again not to mark down all they know about the object. *The question is whether they actually "heard" again the sounds made by, or connected with, the object;* and if so, whether the experience was *vivid* or *faint, complete* or *fragmentary, sustained* or *fleeting, prompt* or *slow* in making its appearance.

Visual, tactual and kinaesthetic images, if such occurred spontaneously, should be reported in answer to the third question; word-images, in answer to the fourth.

Experiment 118. The instructor should proceed in the same manner in order to ascertain *the tactual and kinaesthetic images* which the students can arouse *deliberately,* as well as those of the visual, auditory, and verbal kind which come to them spontaneously while they are thinking of the *same* object. In other words, the *same* stimulus-word as that used in the two preceding exercises, should be employed also in this.

Experiments 119, 120 and 121. The last three experiments should be performed over again with these two

differences: 1) *another stimulus-word* should be employed, *but it should be the same in all three experiments;* 2) the instructor should not pronounce the word, but *write* it on a slate and exhibit it for about two seconds to the class. For the rest the mode of procedure is the same as before.

Experiment 122. After a preliminary warning to be "ready", the instructor employs one of the same two stimulus-words at the end of a short sentence. He proposes the latter to the class by simply pronouncing it. The class should know that one of the two words used before, will be employed now in the manner indicated, but not which of the two. Immediately after this sentence the instructor proposes another equally short sentence. For instance: "This morning I took the *street-car*. It was raining." The instruction to the class is to pay attention to the meaning of the two sentences and to imagine, if possible, the object signified by the stimulus-word, when the latter is actually pronounced and understood.

This experimental arrangement directs the attention of the students to a definite familiar word, but only as part of a whole sentence. Under these conditions, moreover, it is impossible to dwell longer on the sensible object signified by the word than is necessary to understand the sentence in which it occurs. For the next sentence, too, must be understood. *Consequently in the present experiment we approach more closely the conditions under which images arise in our minds when during a conversation we listen to somebody speaking to us and understand what he says.*

Immediately upon the proposal of the two sentences each student is to answer these two questions:

First question: Did you understand the meaning of the two sentences, and in particular that of the stimulus-word? As an affirmative answer to this question simply write down the two sentences, if not word for word, at least as to the meaning expressed by them, and underline the stimulus-word.

Second question: What images, visual, auditory, tactual or kinaesthetic, arose in your mind, when the stimulus-word was pronounced and actually understood? If no images of any kind worthy of the name presented themselves, state this. At any rate do not write down all you know about the sensible qualities of the object signified by the stimulus-word.

Experiment 123. After a preliminary warning the instructor proposes orally a short sentence, the first word of which signifies a familiar sensible object, and is neither of the two stimulus-words so far employed. For instance: "*The boy* stood on the burning deck." The students are directed to imagine the object signified by this first word, and to understand clearly the meaning of the sentence. They are then to answer without delay the same two questions as in the preceding experiment.

The conditions of the present experiment approach still more closely those in which we find ourselves when listening to some one in conversation. For the students do not know which stimulus-word is coming. The express intention to imagine the object signified by the first word of the sentence is, of course, favorable for the appearance of images; a condition not present in ordinary conversation. Our attention is, as a rule, occupied exclusively with the thought expressed by the speaker.

Experiment 124. After a preliminary warning and at a given signal each student reads silently the scriptural passage printed below, making a deliberate effort to imagine the objects signified by the words printed in italics. Immediately upon one reading of the passage the same two questions are to be answered in writing. The passage is as follows:

"Consider the *lilies,* how they grow: they *labor* not, neither do they *spin.*"

In this experiment we test how far we really imagine sensible objects (and operations) of which we think when reading silently, and that under conditions which are

rather favorable for the arousal of images. The express intention, to arouse images, is the favorable factor which is usually absent.

Experiment 125. After all these exercises are completed according to the instructions comes the most important and simplest of them all, which should not be omitted on any account. It consists in this that the students interchange papers, each reading the introspective reports of his neighbor. If time allows, the papers should be interchanged a second and a third time. It is desirable, in fact, that every student should read the introspective reports of every other one.

This simple exercise will be an experimental demonstration of the two basic facts concerning imagination and thought, which it was our purpose to ascertain by means of the above experiments. *The information which such a glimpse into the inner life of others gives cannot be supplied in any other way. And the information, thus gained, will bring home to the students more forcibly than any doctrinal disquisition can, what the problem of sensationalism really is.*

9. **Results of these Experiments.** The most important result of our experiments is not that they enable us to classify persons according to the so-called types of imagination. Interesting as this result is, it is entirely overshadowed by another which is even more striking. It may be expressed by the three following propositions:

(1) *The different subjects of the experiments disagree hopelessly as to the images which were aroused by the stimulus-words. But all agree perfectly with regard to one internal experience: the thought of the object, signified by each respective stimulus-word.* This is the only experience which is reported uniformly by all. The same word, then, which created a veritable Babylonian confusion of images in the members of the class, conveyed to all one and the same thought, namely of the object signified by the word. Nor is this all. For

(2) *the images* which were actually aroused by the word were—at least in many subjects—*very slow* in presenting themselves. They were, moreover, so *fragmentary, dim* and *shadowy, that they had to be picked out laboriously from the background of attention. The thought, on the other hand, which was conveyed by the word, stood out boldly in the foreground of the attention of all, and that as soon as the stimulus-word was presented.* This thought is the only internal experience which is reported promptly and unhesitatingly by all.

(3) *There is probably no one who experienced on two successive occasions exactly the same images when thinking of one and the same object.*

10. Sensationalism in the Light of these Results. The significance of these results can hardly be overestimated. *According to sensationalism images are not accompaniments of thought, but they are the thought. If this be so, could it possibly be said that the same thought was conveyed to all the members of the class by means, say, of the word "street-car", or that any one of them can convey his own thought to all others by means of the same word?*

When I use the word "street-car", no one is the wiser as to the images which I have in my mind: *I do not, and cannot thus manifest my images.* Nor can I bring it about that every reader of this book should experience the same images as I have, when I use here and now the word "street-car": *I do not and cannot thus impart my images to anybody else.* But every reader "knows" that which I "know". *It is this "knowledge" or "thought", and nothing but this "thought", which I unequivocally manifest as actually present in my mind, and which I just as unequivocally impart to the minds of others by simply using the term "street-car".* And what holds true of this word, holds true of every other word of every language.

If images, then, are thought, as sensationalists maintain, then *words cannot be used as vehicles of thought.* Any attempt to employ them thus must necessarily result in a

Babylonian confusion of thought. This is what sensationalism stands for. Unless, therefore, we wish to stultify ourselves, we cannot accept sensationalism even as a working-hypothesis. The simple fact is, it does not work.

The facts here set forth concerning the use of words as vehicles of thought, are too patent to be gainsaid, and too fundamental—for psychological and all other scientific pursuits—to be rendered doubtful by an appeal to the results of any future and more elaborate experiments which are expected to reverse our decision. For, however elaborate the experimental arrangement may be, and however painstaking and competent the subjects may be in self-observation and making their introspective reports: *the results of such experiments will again have to be couched in words to serve as vehicles of thought. And as long as words remain such vehicles of thought, images are not thought. They will ever remain what they are in the light of our simple class-exercises: mere accompaniments of thought.*

11. The So-Called Types of Imagination. In spite of the fact that no individual agrees perfectly with any other one as to the images he experiences, when thinking of one and the same object, still there are certain regularities to be observed in the introspective reports of our experiments and similar statistical inquiries. It can be said that, in general at least, a certain *kind* of imagery *preponderates* in each one's experience. According as the preponderating images are of the visual, auditory, or tactual and kinaesthetic kind, we speak of the subjects as belonging to the *visual, auditory,* or *kinaesthetic type of imagination.* They have also been called *visualizers* (or *visils), audils,* and *tactils* respectively.

As to the audils, in particular, it should be added that they are not necessarily gifted with musical imagination. The latter is rather a special form of imagination, which will be dealt with in a later paragraph, as it throws very little light on the subject which concerns us now: the relation between images and thought.

The line of demarcation between the said types is far from being a sharp one. There are some, to begin with, who have equal facility in arousing *all* the various kinds of images, and they are said to belong to the "*mixed type*". This, of course, is but another way of saying that they belong to *no distinctive type*. And, what is more important, the kind of imagery which a person experiences depends not only on his *native constitution*, as the term "types of imagination" leads us to suppose, but also on his *acquired habits*, as well as on *the manner in which any particular sensible object most forcibly presents itself*, and last, but not least, on the *direction of voluntary or involuntary attention* in every individual case. *Our simple class-exercises are so devised that all these various influences, modifying the types, can easily be traced in the introspective reports.* This needs no further explanation.

What complicates the matter still further is the fact that there are a good many persons who, on introspection, cannot discover either visual or auditory or tactual-kinaesthetic images, worthy of the name, at least of the sensible objects themselves, of which they are thinking. This is particularly true of such as are given to scientific or philosophic pursuits. The only images they can trace are of the words by which they would outwardly express their thoughts. They are said to belong to the *word-type* of imagination in opposition to the *object-type*, and according as their word-images are visual, auditory, or kinaesthetic in character, *verbal sub-types of imagination* have been distinguished: *auditory, visual,* and *kinaesthetic*. Also these further sub-divisions are taken account of in our class-exercises.

The introspective reports, however, will bear out the statement that also the distinction between these verbal sub-types of imagination is far from being clearly marked in nature. Even that between the object-type and word-type is anything but thoroughgoing, as there is hardly any one, in whose ordinary experience word-images do not play an important role. James (Psych., p. 304) quotes the

report of an extraordinary object-visualizer, whose word-images are just as remarkable. *This subject could look down the mentally seen page and see the words that commence all the lines, and from any one of these words he was able to continue the line.* As a proof he copied a page of La Fontaine 8, IV., from memory, thus:

Etant fait............	Céres.................
Tous.................	Avec.............
A des................	Un fleur..............
Que fit...............	Comme...........

12. Musical Imagination. Musical imagination is, as stated above, a special form of auditory imagination. It deserves special consideration because of the extraordinary development which it has received in modern times.

In its creative form it is especially astonishing in modern composers, particularly those who created their immortal works under peculiarly distressing circumstances. Beethoven, it is well known, wrote his greatest works at a time when he was deaf. Schubert, though not deaf, never heard the most remarkable of his orchestral compositions, except in his imagination: an accomplishment and a misfortune which many of the lesser stars in the musical firmament share with him. Mozart carried all the details of his compositions so accurately in his imagination that "the committing to paper (as he himself testifies) is done easily enough; for everything is, as I said before, already finished; and it rarely differs on paper from what it was in my imagination. At this occupation I can therefore suffer myself to be disturbed; for whatever may be going on around me, I write and even talk, but only of fowls and geese, or of Gretel or Barbel or some such matters" (quoted by Carpenter, Ment. Physiol., p. 272).

In its reproductive form musical imagination is just as marvellous in virtuosi and orchestra-directors. When the famous pianist Hans von Bülow began in the middle of the last century to play from memory in all his recitals and concerts—a thing not dreamt of until then,—he created a veritable sensation. At present no soloist of repute would

think of playing from a copy during a recital or concert. It was, however, as an orchestra-director that the same Hans von Bülow capped the climax. For he directed not only the comparatively simple orchestral works of the classical period by heart, but he did the same thing in the case of the music-dramas of Wagner. Even musicians that can boast of a good musical memory cannot help wondering at such a feat. *How can a man carry all the details of the stupendously complex scores of Wagner so perfectly in his imagination that he can direct his attention to any one of these details, as an orchestra-director must be able to do?* This prodigious feat of Bülow has since been imitated by a number of other orchestra-directors.

To musicians who are thus gifted—or rather, who have developed their natural endowment in this regard by a deliberate effort and constant practice—*the reading of a musical score means their hearing it, so that they can have a concert whenever they like, and any program they like.* Such a thing is unintelligible not only to visualizers, but also to those "audils" whose highest achievement in this regard has been to experience a familiar tune running through their heads.

13. The Real Significance of the "Types of Imagination". Returning now to the connection between images and thought we must say a few words as to the real significance of the doctrine concerning the types of imagination. *It is a gross misrepresentation of facts, if these types of imagination are exaggerated into "types of mind"*, as they have been at times. There is no foundation for such a conception in the facts which we have considered nor in any others that we shall consider later. Moreover, *the classification of individuals which this doctrine implies is at best only a rough one.* The grain of truth contained in the doctrine, and its theoretic significance may be expressed in these two propositions:

1) *The images which different individuals experience when thinking of one and the same object, differ not only*

in many details, but frequently even in kind. This knowledge may be used to advantage in memorizing "by rote".

(2) *The difference in the kind of imagery experienced by different individuals, emphasizes the hopelessness of sensationalism as a working hypothesis.*

For the greater the difference in the images of different individuals, the more hopeless is the attempt of any individual to communicate his images to anybody else by simply using the word which signifies the object of his thought. *He does succeed, however, in thus communicating his thought.* Accordingly **his images are not his thought.**

To put the matter differently. Many an image which we experience when thinking of a definite object, is, on the face of it, irrelevant and sometimes partakes rather of the nature of a distraction, as everybody knows. But *in the light of the foregoing discussions any particular image we may experience on a given occasion, be it of this kind or that, must be said to be irrelevant, as far as the thought is concerned which we express in words. This image is but a hook to which our thought happens to be attached on this occasion. Every other person to whom we communicate our thought attaches the same thought to another hook and, maybe, even to a different kind of hook. It is only sensationalists that are particularly interested in these hooks and in carefully classifying individuals according to these hooks. We are more interested in that which is hooked to them.*

END OF VOL. I.

INDEX OF NAMES AND SUBJECTS

The names of authors whose publications are only referred to in the text, are not contained in the Index.